REPORT NUMBER: RDM/WMA06/00/CON/COMP/0416

PROJECT NUMBER: WP 10974

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

GROUNDWATER EWR REPORT

water & sanitation
Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

OCTOBER 2016

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

GROUNDWATER EWR REPORT

Report Number: RDM/WMA06/00/CON/COMP/0416

OCTOBER 2016

REFERENCE

This report is to be referred to in bibliographies as:

Department of Water and Sanitation, South Africa, October 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Groundwater EWR report. Prepared by: WSM Leshika Consulting (Pty) Ltd. Authored by K. Sami. DWS Report No: RDM/WMA06/00/CON/COMP/0416.

DOCUMENT INDEX

Index Number	DWS Report Number	Report Title
1	RDM/WMA06/00/CON/COMP/0115	Inception report
2	RDM/WMA06/00/CON/COMP/0116	Resource Unit report
3	RDM/WMA06/00/CON/COMP/0216	River EWR report
4	RDM/WMA06/00/CON/COMP/0316	Buffels, Sout, Swartlintjies, Spoeg, Groen Estuary EWR report
5	**RDM/WMA06/00/CON/COMP/0416**	**Groundwater EWR report**
6	RDM/WMA06/00/CON/COMP/0516	BHNR report
7	RDM/WMA06/00/CON/COMP/0616	Wetland EWR report
8	RDM/WMA06/00/CON/COMP/0117	Report on consequences of scenarios
9	RDM/WMA06/00/CON/COMP/0217	EcoSpecs and monitoring report
10	RDM/WMA06/00/CON/COMP/0317	Main Summary report
11	RDM/WMA06/00/CON/COMP/0417	Close-out report
12	RDM/WMA06/00/CON/COMP/0517	Electronic data

DEPARTMENT OF WATER AND SANITATION

CHIEF DIRECTORATE: WATER ECOSYSTEMS

DETERMINATION OF ECOLOGICAL WATER REQUIREMENTS FOR SURFACE WATER (RIVER, ESTUARIES AND WETLANDS) AND GROUNDWATER IN THE LOWER ORANGE WMA

GROUNDWATER EWR REPORT

Approved for RFA by:

……………………………………..

Delana Louw
Project Manager

……………………………………..

Date

DEPARTMENT OF WATER AND SANITATION (DWS)
Approved for DWS by:

……………………………………..

Chief Director: Water Ecosystems

……………………………………..

Date

ACKNOWLEDGEMENTS

Karim Sami (WSM Leshika Consulting Pty (Ltd)) authored the report.

Report editor: Shael Koekemoer

REPORT SCHEDULE

Version	Date
First draft	October 2016
Final	January 2017

EXECUTIVE SUMMARY

BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the provision of professional services to undertake the 'Determination of Ecological Water Requirements for Surface Water (Rivers, Estuaries and wetlands) and Groundwater in the Lower Orange Water Management Area (WMA). Rivers for Africa was appointed as the Professional Service Provider (PSP) to undertake this study.

There is a need to undertake detailed Ecological Water Requirement (EWR) and Basic Human Needs (BHN) studies for various water resource components due to mainly:

- Hydraulic fracturing (HF) that could be undertaken in the Water Management Area (WMA).
- Various water use licence applications.
- The conservation status of various Resources in this catchment; and
- The associated impacts of proposed developments will have on the availability of water.

STUDY AREA

The focus area of the study comprises only the South African portion of the Lower Orange River Catchment. The Eastern Boundary starts where the Vaal River enters the Orange River, and the Western Boundary is the Atlantic Ocean. The study area is downstream of the Upper Orange, Senqu, and the Integrated Vaal River System and as such, affected by the upstream activities in the highly developed river basin. The Orange River forms the border between the Republic of South Africa (RSA) and Namibia to the west of 20 degrees longitude over a distance of approximately 550 km.

PURPOSE OF REPORT

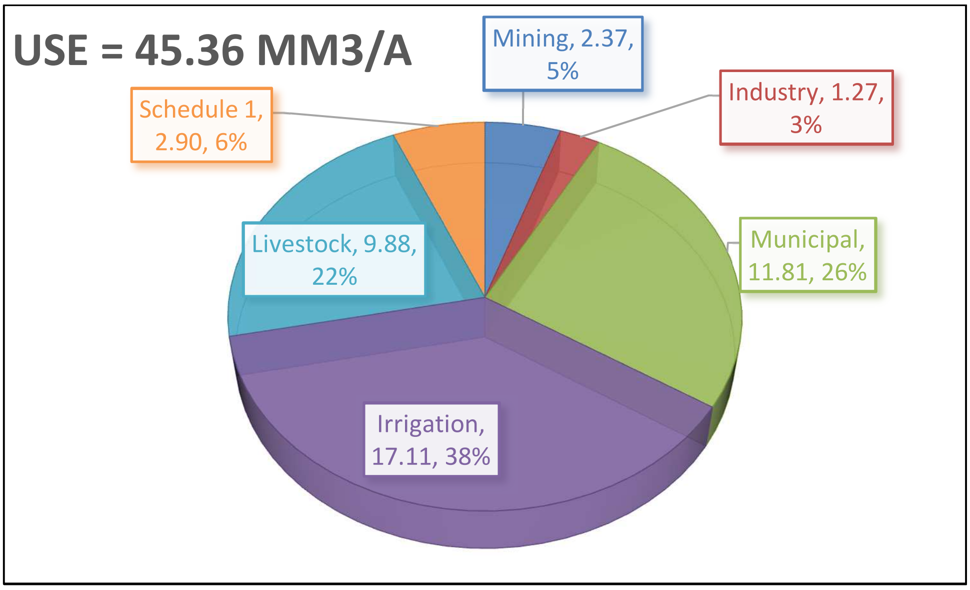
The purpose of this report is to:

- Describe and prioritise the identified Groundwater Resource Units (GRUs).
- Quantify the groundwater component of the Reserve in each GRU.
- Quantify the remaining allocable groundwater in each GRU.

GROUNDWATER USE

Many communities within the WMA are dependent on groundwater for municipal supply. In addition to formal groundwater supply, a large segment of the population is dependent on boreholes and springs. Except for catchments through which the Orange River flows, or is adjacent, the bulk of the region is dependent on groundwater for domestic water supply.

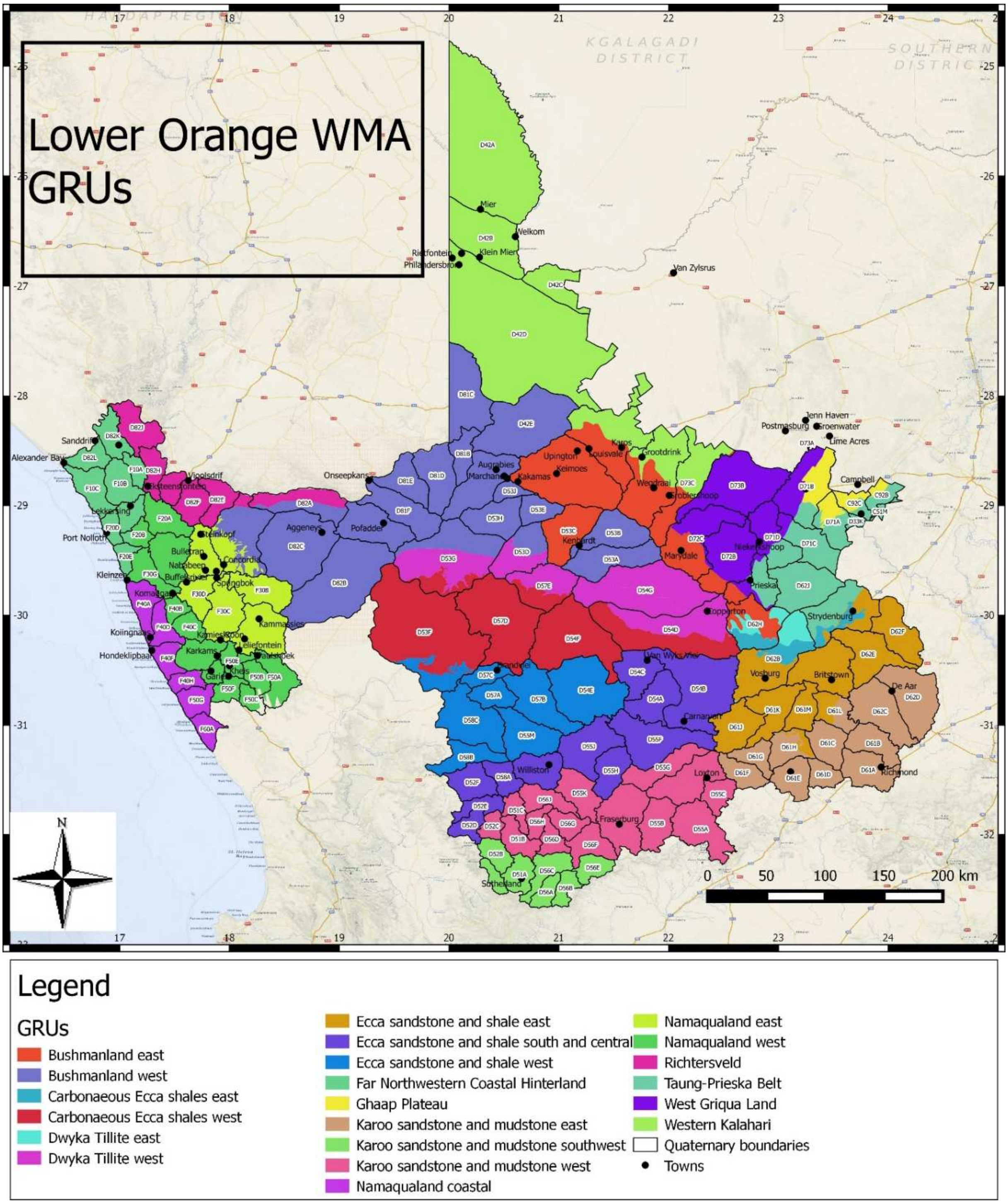
Total groundwater use is 45.36 Mm^3/a, of which 38% is for irrigation. Industry and mining account for 8% of water use, and domestic water use is 32%. The figure below depicts the groundwater use summary in the Lower Orange WMA.



Groundwater use summary

IDENTIFIED GRUs

The figure below provides the identified GRUs.

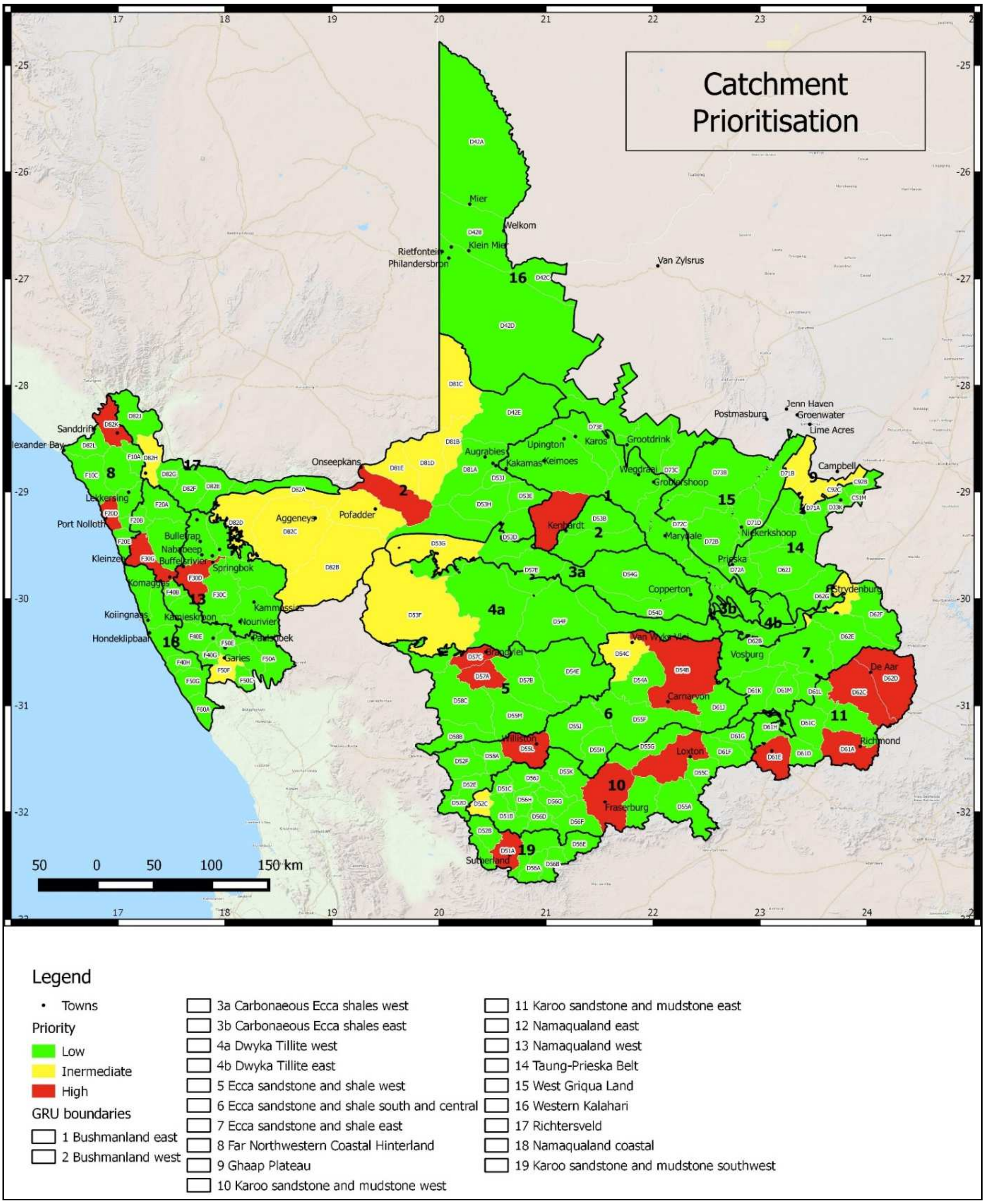


Lower Orange GRU delineation

In order to prioritise and select the most important GRUs, the criteria assessed per RU include:

- Importance of the RU to users (degree of groundwater dependence).
- Threat posed to water resource quality for users (aquifer vulnerability).
- Threat posed to water resource quality for the environment (baseflow).
- Degree of use (stress index).

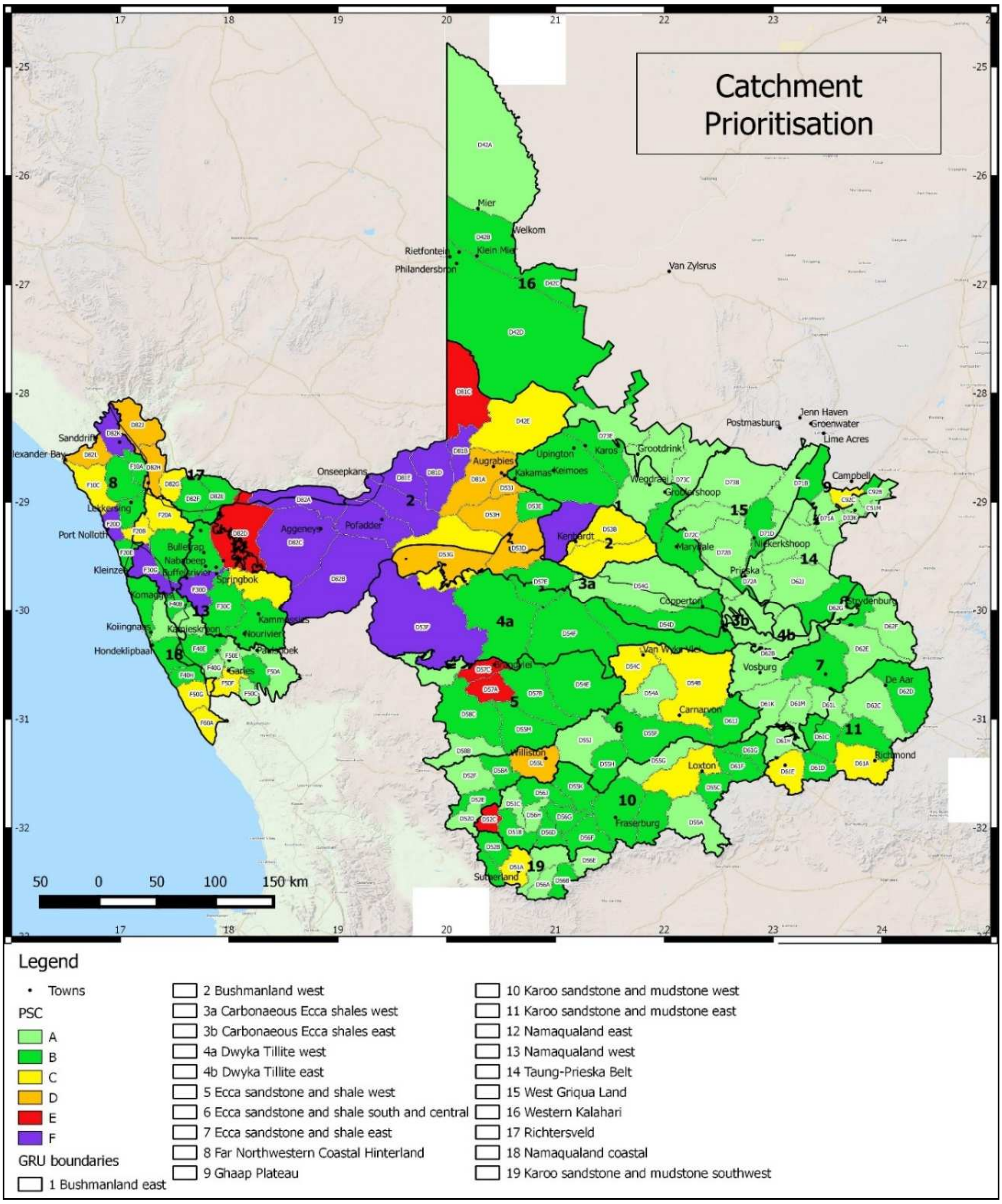
Several areas are identified as being stressed in terms of high stress indices, declining water levels, and sole source dependency. These are depicted in the figure below. Most of the priority catchments are located in the south, the Karoo sandstone and shale GRUs, which are the target area for potential fracking.



Catchment prioritisation of groundwater in the Lower Orange WMA

These GRUs are also classified as sole source aquifers for water supply, and highly dependent on groundwater with an already high stress index. Contamination or large abstractions from fracking or other activities could cause significant deterioration in water supply.

The **Present Status Category** of each Quaternary catchment is shown below.



Present Status Category of groundwater in the Lower Orange WMA

DESCRIPTION OF GRUs

A description of the identified GRUs are provided below and the associated Groundwater Reserve and allocable groundwater information is Tabled.

Bushmanland East

Recharge is from less than 1 mm to over 3 mm/a increasing southeastward with rainfall. The aquifer is fractured in nature with yields of 0.5 - 2 l/s. Groundwater levels average 20 - 25 metres below ground level (mbgl). 70 - 95% of boreholes are potable. Groundwater quality is less saline than in the western area and is generally of class 2. Nitrates, Fluoride, Molybdenum and Arsenic are frequently a problem.

Groundwater dependency is low to moderate and the towns of Marydale and Kenhardt rely on groundwater. Groundwater use is high in D53C, with most of the groundwater use being for regional water supply schemes for the town of Kenhardt. The stress index is below 0.2 in the other Quaternaries. Groundwater use is also low in D72C, where groundwater is used to supply Marydale. Groundwater levels have dropped 6 m in D53C but appear to remain stable. Groundwater levels have dropped 1 m in D72C.

Based on the high level of groundwater dependence, and a high stress index, D53C is considered a high priority catchment in this GRU.

Quat	GW[1] dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53C	77.49	0	0.00384	0.00384	**-0.018***	High
D62H	70.15	0	0.00262	0.00262	2.703	Low
D72A	10.32	0	0.00100	0.00100	0.611	Low
D72B	4.46	0	0.00205	0.00205	0.809	Low
D72C	89.10	0	0.00620	0.00620	1.409	Low
D73C	82.72	0	0.00913	0.00913	1.721	Low
D73D	82.72	0	0.00873	0.00873	0.861	Low
D73E	2.26	0	0.00555	0.00555	0.609	Low
D73F	1.30	0	0.02515	0.02515	0.503	Low

1 Groundwater

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Bushmanland West

Recharge is less than 1 mm/a. Mean groundwater depth increases from less than 20 m near Kenhardt to over 50 m to the west near Aggeneys. Water quality is generally poor and of Class 3 or 4 due to high salinity, with the worst quality water being located in the north from Concordia to Augrabies. Nitrates, Fluoride and Arsenic are frequently a problem. The potability of groundwater is highly variable and ranges from 8 - 80% but is generally low and less than 50%.

The aquifer is considered poor and no communities rely on it for water supply. Groundwater dependency is low to moderate. Groundwater use is primarily for livestock watering, small scale local water supply schemed and Schedule 1 water use. The stress index is high due to livestock water use and many catchments are heavily utilised due to the very low recharge rates. Groundwater levels have dropped 3 m in D81C, which has a stress index of 0.74, but appear to remain stable. Groundwater levels have dropped 1 m in D72C, but also appear to remain stable.

Catchments with a high stress index (>0.65) were considered of intermediate priority since groundwater dependency in the GRU is limited by the poor water quality. Only B81F, in the Pofadder vicinity, has a high stress index and a groundwater dependency exceeding 50%.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D42E	27.59	0	0.01761	0.01761	0.292	Low
D53A	34.14	0	0.00408	0.00408	0.215	Low
D53B	55.76	0	0.00382	0.00382	0.216	Low
D53D	28.58	0	0.00140	0.00140	0.025	Low
D53E	28.34	0	0.00139	0.00139	0.205	Low
D53G	28.94	0	0.00291	0.00291	0.116	Low
D53H	28.34	0	0.00266	0.00266	0.046	Low
D53J	6.21	0	0.00167	0.00167	0.017	Low
D81A	5.77	0	0.01145	0.01145	0.054	Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D81B	36.85	0	0.00111	0.00111	**-0.001***	intermediate
D81C	34.84	0	0.00462	0.00462	0.030	Intermediate
D81D	28.34	0	0.00304	0.00304	0.001	Intermediate
D81E	9.02	0	0.00240	0.00240	**-0.011***	Intermediate
D81F	61.06	0	0.00370	0.00370	**-0.088***	High
D81G	2.50	0	0.00293	0.00293	**-0.003***	Intermediate
D82A	69.43	0	0.00125	0.00125	**-0.042***	Intermediate
D82B	40.14	0	0.00427	0.00427	**-0.060***	Intermediate
D82C	8.51	0	0.00515	0.00515	**-0.051***	Intermediate
D82D	4.06	0	0.00244	0.00244	0.021	Intermediate

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Dwyka Tillite

Recharge is less than 1 mm/a, except in the eastern pocket where rainfall is higher. Groundwater levels are from 18 - 25 mbgl, but above 15 mbgl in the eastern portion. Borehole yields are below 0.5 l/s and the aquifer is considered poor. Groundwater is of unacceptable quality due to salinity of Class 4. Nitrates are frequently a problem, as well as fluorides in the west. The potability of groundwater is poor to unacceptable, except on the NE margins of the GRU, where boreholes are probably drilled through into the Bushmanland rocks. Nearly 80% of boreholes are potable in the Dwyka Tillite East, whereas only 13 - 47% is potable in the Dwyka Tillite West.

Only Copperton obtains water from the aquifer, however, it is a sole source aquifer for the rest of the GRU. Groundwater use is primarily for livestock watering, small-scale local water supply and schedule 1 water use. The stress index is low except in D53G, where some mining occurs at LaFarge gypsum. No groundwater level data are available.

All catchments have a stress index of below 0.65, and only D53G has a moderate stress index. Groundwater dependency for water supply is low except with for D54D, D62B and H, all of which have stress indices of less than 0.1. Consequently, the priority of all catchments, except D53G in the GRU is low.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53D	28.58	0	0.00170	0.00170	0.04734	Low
D53G	28.94	0	0.00368	0.00368	0.07434	Intermediate
D54D	73.18	0	0.00535	0.00535	1.52209	Low
D54G	48.52	0	0.01093	0.01093	2.67637	Low
D57E	32.25	0	0.00242	0.00242	0.35986	Low
D62B	94.18	0	0.00238	0.00238	1.64851	Low
D62H	70.15	0	0.00126	0.00126	1.33939	Low

Ecca Carbonaceous Shale

Recharge is less than 1 mm/a, except in the eastern portion where rainfall is higher. Borehole yields also vary across the GRU, being 0.6 - 0.8 l/s in the west and 0.8 - 1.0 l/s in the east. Groundwater levels are from 15 - 25 mbgl. Groundwater quality is poor and of Class 3. Nitrates and arsenic are frequently of concern in the west, and nitrates in the east. The potability of groundwater is poor to unacceptable in the west, and good in the east. 70 - 90% of boreholes are potable in the east, whereas potability drops to less 15% towards the west.

The aquifer is not utilised for municipal water supply. Groundwater use is for primarily for livestock watering, small-scale local water supply and Schedule 1 water use, except for D53F in the west where salt mining takes place. The stress index is low except in D53F, where it exceeds 1. No groundwater level data are available.

All catchments have a stress index of below 0.3 except D53F, and groundwater dependency for water supply is high, except with for D53G and D57E, where poor groundwater quality precludes its use for water supply. Consequently, the priority of all catchments in the GRU is low, except for D53F, which is considered intermediate due to only a moderate dependence for water supply.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53F	51.46	0	0.00983	0.00983	**-0.25***	Intermediate
D53G	28.94	0	0.00119	0.00119	0.05	Low
D54D	73.18	0	0.00608	0.00608	1.69	Low
D54F	89.19	0	0.00816	0.00816	1.75	Low
D57D	92.00	0	0.01263	0.01263	0.96	Low
D57E	32.25	0	0.00147	0.00147	0.21	Low
D62B	94.18	0	0.00215	0.00215	1.50	Low
D62G	95.21	0	0.00947	0.00947	2.08	Low
D62H	70.15	0	0.00133	0.00133	1.42	Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Ecca Sandstone and Shale West

The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of 0.5 - 1 mm/a. The aquifer is of the fractured type and mean borehole yields are 0.8 - 1 l/s. Groundwater levels are shallow and are 10 - 15 mbgl. Groundwater quality is Good to Marginal and of Class 1 - 2 although nitrates and fluoride can be of concern. The potability of groundwater is variable and declines towards the north near the vicinity of ans. Potability of groundwater in catchments rages from 17 to 100%.

The aquifer is a sole source aquifer and the town of Brandvlei relies on the aquifer. Groundwater use is for livestock watering, and small-scale local water supply, of which Brandvlei is the most significant. The high registered water usage for irrigation in D57A cannot be observed. One of the allocations for irrigation is for water services to Brandvlei. A significant industrial water use is registered by the NRF in D54E. The stress index is low, except for D57A, if the irrigation allocation were to be used. Groundwater levels have dropped 3 m in D81C, which has a stress index of 0.74, but appear to remain stable. Groundwater levels have dropped 3 - 4 m in D57A and B but appear to remain stable.

Catchments with a high stress index (>0.65) were considered of high priority since groundwater dependency in the GRU is very high and the stressed catchments are associated with water supply to Brandvlei.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D53F	51.46	0	0.00137	0.00137	0.069	Low
D54E	90.57	0	0.00692	0.00692	1.585	Low
D55M	92.14	0	0.00365	0.00365	0.506	Low
D57A	91.98	0	0.00176	0.00176	0.022	High

D57B	92.15	0	0.00460	0.00460	1.447	Low
D57C	97.94	0	0.00203	0.00203	0.029	High
D58B	94.88	0	0.00291	0.00291	1.095	Low
D58C	91.90	0	0.00529	0.00529	0.578	Low

Ecca Sandstone and Shale Central and Southwest

The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of from 1 - 3.5 mm/a, increasing towards the east. The aquifer is of the fractured type and mean borehole yields are 1 - 2 l/s. Groundwater levels are shallow and 10 - 15 mbgl. Groundwater quality is highly variable but generally of Class 1 - 2, although fluoride and arsenic can be of concern. There is no natural source of Arsenic in sandstone, and a potential source could be the upwelling of deeper groundwater. The potability of groundwater is variable and declines from nearly 100% to 50% towards the north and west.

The towns of Carnarvon, Van Wyks Vlei and Willistion are dependent on the aquifer. Groundwater use is for small-scale irrigation near the main ephemeral rivers, livestock watering, and small scale to moderate size local water supply. A significant industrial water use is registered by Carnarvon in D54B. The stress index is low, except for D55L due to abstraction by Williston and for significant irrigation. Groundwater levels have dropped 3 m in D81C, which has a stress index of 0.74, but appear to remain stable. Groundwater levels have dropped 15 m in D54B and continue to drop. Water levels in in D55L appear to remain stable. This suggests localised over abstraction could be occurring near Carnarvon in D54B.

The GRU is highly dependent on groundwater for water supply. Catchments with an observed decline in water level and moderate to the moderately high stress index (0.56) were considered priority catchments. D54B was considered of high priority due to the observed water level decline and D55L due to the moderately high groundwater use.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D52D	91.86	0	0.00135	0.00135	1.651	Low
D52E	91.86	0	0.00127	0.00127	1.009	Low
D52F	91.86	0	0.00240	0.00240	1.231	Low
D54A	86.69	0	0.00340	0.00340	1.109	Low
D54B	97.85	0	0.01565	0.01565	3.334	High
D54C	86.69	0	0.00301	0.00301	0.442	Intermediate
D55F	87.21	0	0.00734	0.00734	2.734	Low
D55H	92.15	0	0.00233	0.00233	0.781	Low
D55J	92.15	0	0.00402	0.00402	1.677	Low
D55L	98.84	0	0.00482	0.00482	0.489	High
D58A	91.92	0	0.00160	0.00160	0.470	Low

Ecca Sandstone and Shale East

The Ecca sandstones and shales overlie the carbonaceous shales. They have a recharge of from 4 - 11 mm/a, increasing from west east of Britstown due to increasing rainfall. The aquifer is of the fractured type and mean borehole yields are between 1 - 2 l/s. Groundwater levels are shallow and 7 - 15 mbgl. Groundwater quality is Good and of Class 1, although arsenic can be of concern. There is no natural source of arsenic in sandstone, and a potential source could be the upwelling of deeper groundwater. Groundwater potability is more than 80%.

The towns of Strydenburg, Britstown and Vosburg depend on the aquifer. Groundwater use is largely for small-scale irrigation near the main ephemeral rivers, livestock watering, and moderate size local water supply supplying the main towns in the GRU. The stress index is low and below 0.06 in all catchments. Groundwater levels are stable and only in D62G, in the Strydenburg vicinity, has a water level decline of 5 m been observed. This suggests localised over abstraction could be occurring.

The GRU is highly dependent on groundwater for water supply. D62G was considered of intermediate priority due to the observed water level decline near Strydenburg.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D61H	86.42	0	0.00101	0.00101	0.935	Low
D61J	86.51	0	0.00451	0.00451	3.696	Low
D61K	87.45	0	0.00465	0.00465	4.787	Low
D61L	90.36	0	0.00181	0.00181	2.371	Low
D61M	89.54	0	0.00332	0.00332	3.688	Low
D62A	97.51	0	0.01790	0.01790	7.150	Low
D62B	94.18	0	0.00215	0.00215	5.146	Low
D62E	90.76	0	0.00704	0.00704	9.717	Low
D62F	86.28	0	0.00651	0.00651	12.305	Low
D62G	95.21	0	0.00947	0.00947	3.156	Intermediate

Far Northwestern Coastal Hinterland

The Far Northwestern Coastal Hinterland has recharge of less than 1 mm/a. The fractured aquifer is classified as poor, with borehole yields being low and around 0.1 l/s. Groundwater levels are from 25 - 45 mbgl. Groundwater is of Poor to Unacceptable quality, Class 3 and 4, with high Fluoride levels. Groundwater is of poor quality, except adjacent to the Orange River. This indicates recharge of fresh water from the river. The high salinity precludes groundwater use over large parts of the GRU. The potability is less than 15% in the southern half of the GRU.

Groundwater dependency is low on the coast and close to the margins of the Orange River, but increases inland. The towns of Sanddrift, Port Nolloth, Kuboes and Lekkersing are dependent on groundwater. Groundwater use is primarily for water supply, of which Port Nolloth is the main groundwater user. Additional groundwater is used for livestock. The stress index is high due to the very low recharge rates. D82K and F20D have very high stress indices, however, the aquifers utilised are likely recharged by surface water during flood events, and hence rainfall recharge is not a good indicator of recharge to the aquifers. Groundwater levels in F20D do not indicate stress and have risen from 1984 to present.

The GRU is only marginally dependent on groundwater for water supply due to the poor quality; consequently, the catchments are of low priority, except for D82K and F20D, which are used for local water supplies.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D82K	81.85	0	0.00223	0.00223	**-0.04***	High
D82L	2.64	0	0.00188	0.00188	0.02	Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
F10A	34.83	0	0.00005	0.00005	0.06	Low
F10B	34.83	0	0.00012	0.00012	0.14	Low
F10C	34.83	0	0.00013	0.00013	0.09	Low
F20B	44.29	0	0.00005	0.00005	0.01	Low
F20C	81.67	0	0.00217	0.00217	0.15	Low
F20D	54.96	0	0.00032	0.00032	**-0.18***	High
F20E	67.55	0	0.00010	0.00010	0.17	Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Ghaap Plateau

The Ghaap Plateau GRU is underlain by Ghaap Plateau dolomites, which are covered by Kalahari and Tertiary sediments in some places. It is the most significant aquifer in the WMA in terms of recharge, permeability and aquifer storage. Recharge is from 7 - 10 mm/a. The aquifer is of the karts type and mean borehole yields are 1.5 - 2 l/s. Groundwater levels are 15 - 20 mbgl. Groundwater quality is of Class 1, and nitrates are the only nuisance constituent. Groundwater is of Good quality and mostly of Class 1. The potability of groundwater is almost 100%.

Griekwastad is dependent on the aquifer. Groundwater use is primarily for water supply, of which Campbell and Griekwastad are the main municipal users. Irrigation also occurs, as does mining at Lime Chem Resources. The stress index is low due to the high recharge rates of the dolomites. Groundwater levels in D71B show that water levels are stable since 2001.

The GRU is moderately dependent on groundwater for water supply, except for D71B, which is heavily dependent. Due the dolomitic nature of the terrain, the catchments are considered of intermediate priority in spite of the low stress index.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
C92B	51.73	0	0.00725	0.00725	0.880	Intermediate
C92C	6.18	0	0.01967	0.01967	1.974	Intermediate
D71A	61.22	0	0.00192	0.00192	1.909	Intermediate
D71B	92.62	0	0.00687	0.00687	4.331	Intermediate

Karoo Sandstone and Shale West

Recharge increases from 1 - 3 mm/a from north to south, being highest in the Sutherland vicinity. The aquifer is of the fractured type and mean borehole yields are 1 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 15 mbgl. Groundwater quality is of Class 1 - 2, however arsenic and molybdenum can be encountered. The potability of groundwater is over 90%.

The aquifer is a sole source aquifer and Fraserburg and Loxton rely on groundwater. Groundwater use is primarily for irrigation, however, water supply to Fraserburg and Loxton are a significant component of the water use. The stress index is variable but is high in D52C due to irrigation. Groundwater levels in D55D and D55E indicate dropping water levels in the Loxton vicinity and Fraserburg, despite only low to moderate stress indices in those catchments, suggesting that localised dewatering is occurring due to local aquifers not being connected hydraulically to the remainder of the catchment.

The GRU is highly dependent on groundwater for water supply, consequently, catchments used for water supply are considered of high priority if they exhibit dropping water levels. D52C warrants being considered of intermediate priority due to a high stress index resulting from irrigation.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D51B	92.14	0	0.00176	0.00176	1.335	Low
D51C	92.02	0	0.00103	0.00103	0.523	Low
D52C	92.1	0	0.00093	0.00093	0.103	Intermediate
D55A	94.33	0	0.01137	0.01137	3.154	Low
D55B	91.73	0	0.00260	0.00260	1.770	Low
D55C	92.09	0	0.00339	0.00339	1.788	Low
D55D	96.33	0	0.00710	0.00710	2.107	High
D55E	98.78	0	0.00664	0.00664	1.820	High
D55G	88.27	0	0.00362	0.00362	1.195	Low
D55K	92.15	0	0.00253	0.00253	0.847	Low
D56D	92.15	0	0.00123	0.00123	0.556	Low
D56F	92.15	0	0.00207	0.00207	0.861	Low
D56G	92.15	0	0.00130	0.00130	0.555	Low
D56H	92.15	0	0.00091	0.00091	0.296	Low
D56J	92.15	0	0.00188	0.00188	0.749	Low

Karoo Sandstone and shale East

Recharge increases from 3 mm/a near Loxton, to nearly 12 mm/a around De Aar. The aquifer is of the fractured type and mean borehole yields are 1.5 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 15 mbgl. Groundwater quality is Good to Marginal, of Class 1 - 2, with the marginal groundwater found in the South East between Richmond and De Aar. Arsenic and Molybdenum can be encountered. The potability of groundwater is over 90%, however some boreholes exhibit unexpectedly high salinity, which could be indicative of upwelling deeper groundwater. Since the GRU forms a high lying recharge area with no potential for groundwater flow from upgradient, it has higher recharge than the Karoo further west, and the rocks are of a continental environment not of marine origin, high salinity would not be expected, as is the case in over 90% of boreholes. The pockets of higher salinity could indicate areas of upwelling groundwater.

The aquifer is a sole source of supply for De Aar, Richmond, and Victoria West. Groundwater use is primarily for irrigation, however, water supply to De Aar, Richmond and Victoria West are a significant component of the water use. The stress index is low to moderate. Groundwater levels in D61A near Richmond indicate dropping water levels despite only a moderate stress index, suggesting that localised dewatering is occurring due to local aquifers not being hydraulically connected to the remainder of the catchment. Water levels in D61E and in the De Aar vicinity in D62C and D62D remain stable over the long term despite periods of dropping water levels during dry periods.

The GRU is highly dependent on groundwater for water supply, consequently, catchments used for water supply are considered of high priority if they exhibit dropping water levels.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D61A	89.11	0	0.00892	0.00892	4.069	High
D61B	85.45	0	0.00428	0.00428	3.404	Low
D61C	86.66	0	0.00390	0.00390	4.264	Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D61D	86.42	0	0.00216	0.00216	1.392	Low
D61E	96.36	0	0.00827	0.00827	2.949	High
D61F	86.42	0	0.00290	0.00290	1.659	Low
D61G	86.42	0	0.00250	0.00250	1.677	Low
D61H	86.42	0	0.00263	0.00263	2.388	Low
D61L	90.36	0	0.00181	0.00181	2.405	Low
D62C	96.04	0	0.01091	0.01091	9.951	High
D62D	98.97	0	0.02021	0.02021	15.719	High

Namaqualand East

Recharge is from less than 1 mm to 2 mm. The aquifer is of the fractured and weathered type and mean borehole yields are 0.5 - 2 l/s. Groundwater levels are from 12 - 30 mbgl. This GRU was separated from the rest of Namaqualand Groundwater Region due to a higher water levels and recharge than the rest of Namaqualand and a better water quality class, which is of Class 2 - 3, for domestic purposes. Groundwater is of very variable quality, however, approximately 50% of boreholes are potable. Arsenic is present in groundwater.

Springbok, Kammassies and Paulshoek utilise groundwater, and groundwater use is primarily for water supply for all communities between Kamieskoon and Springbok. The stress index is high in F30D due to abstraction for Springbok. Groundwater level data is of too short a duration to observe water level trends. The groundwater stress index is high in D82D; however, it is uncertain if this can be attributed to too low a recharge estimate for the Quaternary, since much of the remainder of the catchment lies in the drier Bushmanland West GRU that has lower recharge.

The GRU is only moderately dependent on groundwater for water supply, consequently, only catchments where water supply result in a high stress index are considered of high priority.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D82D	4.06	0	0.00119	0.00119	0.010	Low
F30A	43.41	0	0.00613	0.00613	0.694	Low
F30B	44.29	0	0.00152	0.00152	0.184	Low
F30C	81.67	0	0.00310	0.00310	1.102	Low
F30D	54.96	0	0.00258	0.00258	**-0.326***	High
F30E	67.55	0	0.00418	0.00418	0.386	Low

Namaqualand West

Recharge is less than 1 mm but can range to over 3 mm in the Garies vicinity due to higher rainfall in the highlands. The aquifer is of the fractured and weathered type and mean borehole yields are low, being 0.1 - 0.5 l/s. Groundwater levels are from 12 to 50 mbgl, being deeper near the coast. Groundwater is generally of Poor to Unacceptable quality, Class 3 - 4. Arsenic and Molybdenum are also present. Groundwater can be of very variable quality, and areas of Class 0 - 2 water also exist, however, less than 40% of boreholes are potable.

The Garies cluster to Kamaggas is reliant on groundwater and most groundwater use is for water supply for the communities of Kamaggas and Garies. De Beers and Bontekoe mine also are significant water users. The stress index is low, except in F30G where mining takes place. Kamaggas also abstracts water from this catchment, however, at a significant distance from De

Beers. No water level data is available to determine the level of stress. Groundwater level data in other catchments do not indicate declining water levels.

The GRU is moderately to heavily dependent on groundwater for water supply, consequently, where abstraction results in a high stress index, those catchments are considered of high priority.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
F20A	43.41	0	0.00038	0.00038	0.132	Low
F20B	44.29	0	0.00016	0.00016	0.039	Low
F30F	46.63	0	0.00109	0.00109	0.221	Low
F30G	94.23	0	0.00186	0.00186	**-0.544***	High
F40B	49.54	0	0.00039	0.00039	0.086	Low
F40C	82.12	0	0.00194	0.00194	0.711	Low
F40E	93.37	0	0.00243	0.00243	1.207	Low
F40G	97.78	0	0.00062	0.00062	0.430	Low
F50A	70.91	0	0.00356	0.00356	0.677	Low
F50B	73.68	0	0.00046	0.00046	0.494	Low
F50C	64.67	0	0.00086	0.00086	0.353	Low
F50E	96.7	0	0.00161	0.00161	1.015	Low
F50F	96.37	0	0.00117	0.00117	0.638	Intermediate

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Taung-Prieska Belt

Recharge is from 3.5 mm/a near Prieska rising to 9.5 mm/a near Douglas. The aquifer is of the fractured type and mean borehole yields are 0.5 - 1.5 l/s. Groundwater levels are 15 - 20 mbgl. Groundwater quality is of Class 1 - 2, which is Good to Marginal, however, elevated nitrates can occur. Class 3 water is found in D72A near Prieska. The potability of groundwater ranges from 76% near Prieska to 100%.

No towns rely on groundwater. Groundwater use is primarily for irrigation and livestock, with the major towns obtaining water from the Orange and Vaal systems. The stress index is low due to the low level of groundwater usage. Groundwater levels in D62G and D72A indicate that water levels are stable.

The GRU is moderately to heavily dependent on groundwater for Schedule 1 water use in areas at a distance from Orange River water. However, due to the low stress indices, all of the catchments are considered of low priority.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
C51M	53.90	0	0.00748	0.00748	0.523	Low
C92B	51.73	0	0.01697	0.01697	2.121	Low
C92C	6.18	0	0.01009	0.01009	1.268	Low
D33K	7.56	0	0.00219	0.00219	0.924	Low
D62G	95.21	0	0.02229	0.02229	4.398	Low
D62J	70.52	0	0.00633	0.00633	6.384	Low
D71A	61.22	0	0.00340	0.00340	3.353	Low
D71B	92.62	0	0.00269	0.00269	1.824	Low
D71C	64.61	0	0.00507	0.00507	3.805	Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D71D	87.25	0	0.00320	0.00320	1.719	Low
D72A	10.32	0	0.00289	0.00289	1.738	Low

West Griqualand

Recharge is from 2 - 6 mm/a and increases from west to east. The aquifer is of the fractured type and mean borehole yields are low, being 0.5 - 1 l/s. Groundwater levels are 20 - 35 mbgl. Groundwater quality is of Class 1 - 2 but elevated nitrates can occur. Towards the west, south of the Orange River, some Class 2 and 3 boreholes are found near the margins of the Bushmanland East GRU. The potability of groundwater is over 90%.

Niekerkshoop is reliant on groundwater. Otherwise, groundwater use is primarily for irrigation and livestock. The stress index is low due to the low level of groundwater usage. Groundwater levels only indicate a drop of about 1 m over the period of record.

The GRU is moderately to heavily dependent on groundwater for Schedule 1 water use and for Niekerkshoop, however, due to the low stress indices, all of the catchments are considered of low priority.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D71B	92.62	0	0.00856	0.00856	5.75	Low
D71C	64.61	0	0.00087	0.00087	0.65	Low
D71D	87.25	0	0.00516	0.00516	2.42	Low
D72A	10.32	0	0.00123	0.00123	0.66	Low
D72B	4.47	0	0.01064	0.01064	4.08	Low
D72C	89.10	0	0.00615	0.00615	1.67	Low
D73B	57.83	0.11163	0.01768	0.12931	11.39	Low

Western Kalahari

The GRU consists of largely of Kalahari duneveld. The Molopo River flowing through the GRU does generate sufficient flow to reach the Orange River and much of the flood is lost by evaporation, or seepage to recharge the sand aquifer. This process makes recharge estimation based purely on rainfall problematic and recharge may be higher than estimated. Recharge is less than 1 mm. Three aquifer types exist:

- The surficial intergranular Kalahari sand aquifer, which has yields of 0.5 - 2 l/s;
- The Stampriet confined aquifer system, which underlies the Kalahari in the north and fractured in nature. It has low yields of 0.1 - 0.5 l/s; and
- Other fractured aquifers of the Dwyka, Brulpan Volop and Koras Groups, which have yields of 0.5 - 2 l/s.

Groundwater levels are from 25 to 90 mbgl, being deepest in the northern Kalahari.

The Stampriet Transboundary Aquifer System (STAS) is an international aquifer that stretches from Central Namibia into Western Botswana and into South Africa. It covers a total area of 86 647km², for which 73% of the area is in Namibia, 19% in Botswana, and 8% is in South Africa. It is unexposed at surface in South Africa and underlies the Kalahari sands in D42A-D. Over 20 million m³/year are abstracted rom the Stampriet aquifer, most of which occurs in Namibia (over 95%). The largest consumer of water is irrigation (~46%) followed by stock watering (~38%) and domestic use (~16%).

In the Southeastern quadrant of the aquifer within South Africa, groundwater seeps upward from the confined aquifers and discharges into the Kalahari Formations, from where it evaporates in pans and wetlands. Groundwater salinity in this zone therefore is rather high.

In South Africa, the aquifer has only limited potential for further development because, apart from the poor water quality, the permeability and storativity is low.

Groundwater quality in the GRU generally of Poor to Unacceptable quality, being largely of Class 3 and 4, and only improves in the SE around Karos and Grootdrink in the D73 catchments, where it is of Class 2. In the Kalahari sands, groundwater can be very alkaline. Nitrates are fluorides are elevated in the GRU. In the D73 catchments the Kalahari sands are thinner and recharge is higher hence groundwater quality improves. Fresh groundwater also exists near Philandersbron, where the Kalahari cover disappears and Karoo rocks are exposed, and wetlands exist. The potability of groundwater is about 20% over large parts of the region, and nearly 80% in the D73 catchments.

The Rietfontein and Mier cluster of communities are reliant on groundwater from fractured Dwyka aquifers. Groundwater use is primarily for livestock and water supply, which the remainder for salt mining. The stress index is low due to the low level of groundwater usage. Groundwater levels only indicate a slight drop of about 1 m over the period of record.

The GRU is heavily dependent on groundwater for Schedule 1 water use and for water supply to the towns in the Kalahari Panhandle. However, due to the low stress indices, all of the catchments are considered of low priority.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D42A	84.53	0	0.00623	0.00623	12.732	Low
D42B	91.94	0	0.00707	0.00707	1.017	Low
D42C	72.42	0	0.04201	0.04201	1.104	Low
D42D	75.92	0	0.03552	0.03552	8.979	Low
D73C	82.72	0	0.00931	0.00931	3.172	Low
D73D	5.47	0	0.00687	0.00687	0.677	Low
D73E	2.26	0	0.00593	0.00593	0.674	Low

Richtersveld

Recharge is less than 1 mm. The aquifer is of the fractured and weathered type and mean borehole yields are very low, being 0 - 0.1 l/s. Groundwater levels are from 30 - 50 mbgl, being deeper to the east. Groundwater is of Marginal to Unacceptable quality, Class 2 - 4. The potability of groundwater ranges from 0 - 60%.

Eksteenfontein is the only community reliant on groundwater. Groundwater use is primarily for livestock and water supply. The stress index is moderate to high due to the very low recharge rates.

The GRU is only moderately dependent on groundwater, except for D82H, where Eksteenfontien derives its water supply from boreholes. This catchment is considered to be only of intermediate importance due to the moderate stress index of 0.42.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D82A	69.43	0	0.00110	0.00110	**-0.013***	Low
D82D	4.06	0	0.00022	0.00022	0.002	Low
D82E	47.29	0	0.00091	0.00091	0.118	Low
D82F	8.09	0	0.00098	0.00098	0.148	Low
D82G	6.29	0	0.00094	0.00094	0.049	Low
D82H	96.87	0	0.00044	0.00044	0.037	Intermediate
D82J	34.83	0	0.00006	0.00006	0.037	Low

Namaqualand Coastal

Recharge is from less than 1 mm to 2 mm. The aquifer is of the fractured and weathered type but mean borehole yields are very low, being less than 0.1 l/s. Groundwater levels are from 40 - 50 mbgl. Groundwater is generally of Class 3 and 4, Poor to Unacceptable, except in the north, in F40A and F40D, where Class 2 and 3 water exists. The potability of groundwater is less than 30%.

The aquifer is a sole source of supply for Kleinzee, Hondeklipbaai and Kolingnaas. Groundwater use is primarily for livestock and water supply. The stress index is low to moderate due to the small population and very low recharge rates.

The GRU moderately to heavily dependent on groundwater despite the poor quality, as no surface water source is available. The catchments are considered to be of low importance due to the low to moderate stress indices.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
F40A	88.89	0	0.00117	0.00117	0.831	Low
F40D	62.3	0	0.00066	0.00066	0.591	Low
F40F	97.31	0	0.01048	0.01048	0.363	Low
F40H	73.68	0	0.00040	0.00040	0.074	Low
F50G	73.68	0	0.00059	0.00059	0.077	Low
F60A	81.59	0	0.00103	0.00103	0.065	Low

Karoo Sandstone and Shale Southwest

The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Small volumes of baseflow potentially exist in the Sutherland vicinity due to higher rainfall, however, any baseflow is lost further down the channel. Recharge increases from 3 - 8 mm/a from north to south, being highest in the Sutherland vicinity. The aquifer is of the fractured type and mean borehole yields are 1.5 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 13 mbgl.

Groundwater quality is of Class 1 - 2, however, high fluorides can be encountered. The potability of groundwater is over 90%.

The aquifer is a sole source of supply for Sutherland. Groundwater use is primarily for irrigation, however, water supply to Sutherland is a significant component of the water use. The stress index is low, but is moderate in D51A due to irrigation and water supply to Sutherland. Groundwater levels in D51A indicate dropping water levels 12 m below original water levels, despite only a moderate stress index, suggesting that localised dewatering is occurring due to local aquifers not being connected hydraulically to the remainder of the catchment.

The GRU is highly dependent on groundwater for water supply, consequently, catchment D51A with a dropping water level is considered of high priority.

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	Reserve: GW component (Mm^3)	Allocable GW (Mm^3)	Priority
D51A	99.64	0.1594	0.00347	0.16287	2.438	High
D52A	92.15	0	0.00078	0.00078	1.808	Low
D52B	92.15	0	0.00130	0.00130	1.840	Low
D56A	92.15	0	0.00104	0.00104	1.922	Low
D56B	92.06	0	0.00107	0.00107	1.503	Low
D56C	92.15	0	0.00188	0.00188	1.928	Low
D56E	92.15	0	0.00136	0.00136	0.888	Low

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

BH	Bore Hole
BHN	Basic Human Needs
BHNR	Basic Human Needs Reserve
CD: WE	Chief Directorate: Water Ecosystems (Name change from CD: RDM)
DWA	Department Water and Sanitation (Name change applicable after April 2009)
DWAF	Department Water and Sanitation and Forestry
DWS	Department of Water and Sanitation (Name change applicable after March 2014)
EC	Electrical Conductivity
EWR	Ecological Water Requirements
GRA II	Groundwater Resource Assessment Phase II
GRDM	Groundwater Resource Directed Measures
GRU	Groundwater Resource Unit
GW	Groundwater
HF	Hydraulic Fracturing
ICP	Inductively Coupled Plasma
ISP	Internal Strategic Perspective
IUA	Integrated Units of Analysis
l/c/d	Litres per capita per day
Ma	Mega-annum or million annums
Mamsl	Metres above mean sea level
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbgl	metres below ground level
mm/a	Millimetres per annum
NFEPA	National Freshwater Ecosystem Priority Area
NGA	National Groundwater Archive
NWA	National Water Act
ORASECOM	Orange-Senqu River Commission
PSP	Professional Service Provider
RDM	Resource Directed Measures
RQO	Resource Quality Objective
RU	Resource Unit
SFR	Streamflow Reduction
STAS	Stampriet Transboundary Aquifer System
TDS	Total Dissolved Solids
TOR	Terms of Reference
WARMS	Water Authorisation and Management System
WMA	Water Management Area
WMS	Water Management System
WR2012	Water Resources of South Africa, 2012 Study
WRSM2000	Water Resources Simulation Model 2000

1 INTRODUCTION

1.1 BACKGROUND

The Chief Directorate: Water Ecosystems (CD: WE) of the Department of Water and Sanitation (DWS) initiated a study for the provision of professional services to undertake the 'Determination of Ecological Water Requirements for Surface Water (Rivers, Estuaries, and Wetlands) and Groundwater in the Lower Orange Water Management Area (WMA). The appointed Professional Service Provider (PSP) to undertake this study was Rivers for Africa.

As per the Terms of Reference (TOR), there is a need to undertake detailed Ecological Water Requirement (EWR) and Basic Human Needs (BHN) studies for various water resource components due to mainly:

- Planned hydraulic fracturing (HF) undertaken in the WMA.
- Various water use licence applications.
- The conservation status of various Resources in this catchment; and
- The associated impacts of proposed developments will have on the availability of water.

The National Water Act (NWA) (Act No. 36 of 1998) provides a legal framework for the effective and sustainable management of South Africa's water resources. The aim of protecting water resources is to ensure that water is available for current and future use. Protection therefore involves the sustaining of a certain quantity and quality of water to maintain the overall ecological functioning of rivers, wetlands, groundwater and estuaries. Chapter 3 of the NWA (parts 1, 2 and 3) of the NWA introduces a series of measures, which together intend to protect all water resources. These measures, referred to as Resource Directed Measures (RDM), and in the case of where they are related to groundwater, as Groundwater Resource Directed Measures (GRDM). These measures include Classification, Quantification of the Reserve and Resource Quality Objectives (DWA, 2011). The "Reserve" as defined in the NWA constitutes the quantity and quality of groundwater required to:

"*Satisfy Basic Human Needs (BHN) by securing a basic water supply for people who are now or who will in the foreseeable future be dependent on groundwater; and Protect aquatic ecosystems, to ensure ecologically sustainable development and use of the relevant water resource. This is known as an Ecological Water Requirement (EWR) and is essentially the contribution from groundwater towards maintaining baseflow to rivers*."

The GRDM process allows the determination of the allocable groundwater portion (groundwater available after consideration of the BHN and EWR Reserves and existing groundwater use). This can be used to address current, as well as future, water use license applications.

1.2 TERMS OF REFERENCE

The study objectives as defined by the TOR are as follows:

- The determination of the water quantity and quality component of the EWR and BHN for the rivers at various EWR sites.
- The determination of the water quantity and quality component of the EWR and BHN for the priority wetlands, pans and lakes, where applicable.
- The determination of the water quantity and quality component of the EWR and BHN of estuarine freshwater requirements for each identified estuary; and

- The determination of the groundwater quantity and quality component of the EWR and BHN for each identified resource unit/quaternary catchment in the study area.

The TOR stipulated the use of the 8-step procedure to determine the Reserve.

1.3 SCOPE OF WORK

The TOR outlined a set of tasks that had to be completed in 24 months. Tasks relating to the GRDM process are outlined below.

1.3.1 Task 1: Project Inception (Initiate RDM Study)

Step one of the Reserve process describes the inception phase during which project planning and process integration takes place. The objective of this task is to produce a concise, clear and unambiguous Inception Report. This is required to ensure the Client, programme manager and consultants are clear as to the deliverables, timing and budget of the programme. This step runs concurrently with the Water Resources Analysis task so that the identified gaps, and how they are be dealt with, are included in the Inception report (Report RDM/WMA06/00/CON/COMP/0115).

1.3.2 Task 2: Define Resource Units

The TOR states: 'Conduct site selection and delineation of resource units/integrated units of analysis.' Integrated Units of Analysis (IUAs) forms part of the Classification process and consists of various Resource Units (RUs). As results during the Reserve process are not specific for the IUA as a whole but focusses on the RUs within the IUA, the focus of this task is on the delineation of RUs.

Groundwater information captured in Report RDM/WMA06/00/CON/COMP/0116 followed the specifications outlined in the TOR and included a map of significant Groundwater Resource Units (GRUs), used during the compilation of IUAs. Based on the following criteria, GRUs and subdivision beyond Quaternary catchment level were identified:

- The role of groundwater in terms of maintaining baseflow or wetness to rivers, wetlands and estuaries, especially when baseflow originates from specific geological formations.
- Geological conditions which result in large difference in borehole yield and or water quality.
- Topography.

1.3.3 Task 4: Step 4: Quantify EWRs

Groundwater: Identify catchments where baseflow contributes to rivers and estuaries utilising data from Water Resources South Africa, 2012 (WR2012). These catchments require more detailed rainfall runoff and rainfall baseflow simulations.

This Task is the focus of the report and the assessment of groundwater components of relevance to the Reserve consists of the following for each GRU following TOR guidelines:

- Recharge: Since recharge is the primary source driving the groundwater reserve, information was obtained from existing sources like Groundwater Resource Assessment Phase II (GRA II) (DWAF, 2006a), existing reports and maps. In addition, where gauged catchments with baseflow exist, these were used to derive monthly time series of recharge and estimates of threshold monthly precipitation when recharge occurs using the Water Resources Simulation Model 2000 (WRSM2000) (Pitman *et al.*, 2006). This relationship was used to estimate recharge in ungauged catchments.

- Baseflow: Baseflow, where it exists, was simulated using WRSM2000 and calibrated against gauging weirs. Where no gauging weirs exist, parameters were transferred from gauged catchments of similar conditions.
- Alluvial aquifers: For alluvial aquifers of local importance that are recharged by streamflow, WRSM monthly flows were utilised as inputs to a sand aquifer hydraulic model to estimate recharge and sustainable yields based on the time series of flows. Calibration was undertaken against any existing water level data. This was limited to a maximum of two alluvial aquifers.
- Groundwater use: Existing groundwater use affects the groundwater stress index and allocable groundwater. Groundwater use for water supply was quantified using Water Authorisation and Management System (WARMS) data and data in the All Towns studies. Irrigation from groundwater was identified from WARMS and the quantifies verified by comparing registered use with irrigation area using Google Earth.
- Allocable groundwater: Available groundwater volumes were calculated based on recharge, the portion of baseflow required for EWR, the Basic Human Needs reserve and current estimated groundwater use.
- Groundwater quality: The potable groundwater varies from less than 10% in some Quaternaries to nearly 90%. Existing data from the National Groundwater Archive (NGA) and historic reports was utilised to identify catchments with water quality issues. Lithology and rain zones defined water quality investigation. Catchments and lithologies with good water quality were identified and highlighted, if under consideration for HF licences.
- Hydraulic fracturing: HF could be a potential issue in areas where groundwater is the sole source of supply, where good quality groundwater exists and yields are suitably high enough for exploitation. Where HF may pose a risk to water supply, these areas were delineated as zones.
- Estuaries/wetlands: At important estuaries where groundwater interaction is significant in maintaining water quality, groundwater inflows were determined using simulations in MODFLOW. A model requires data on permeability and water levels for calibration. Where such data is unavailable, a spreadsheet model based on WRSM2000 inflows and baseflow was utilised to derive a water balance for the estuary. For budgeting purposes, this was limited to two estuaries.

1.3.4 Task 6: EcoSpecs and Monitoring

Monitoring programme: The monitoring programme will be set up for the EWR sites and the estuary. The estuary and EWR O5 has been included in a detailed monitoring programme as part of the 2013 EWR study and will be updated to include the additional EWR sites, as well as the five additional estuaries. Any updates required for the Orange River estuary will be included. Although not part of the Reserve steps, the TOR has requested the compilation of a monitoring programme also for groundwater resources.

Future monitoring requirements for groundwater will be identified while undertaking the project. Key Indicators of where additional monitoring is needed but not already available will include:

- Stressed catchments requiring water use and water level monitoring.
- Catchments where baseflow exists and is significant to the EWR, but gauging data and water level data is unavailable.
- Good groundwater quality areas where HF may occur.
- Wetlands and estuaries, where groundwater inflows are suspected to exist but water level data is unavailable.

1.3.5 Level of confidence required

The TOR called for a comprehensive level of determination for the EWR and BHN components of groundwater.

1.3.6 Groundwater quality

During the Reserve process, groundwater quality issues are not specifically addressed and as a result, no method is provided to address the groundwater quality component of the Reserve. However, groundwater quality aspects are generally addressed as part of the description of the Study Area and in the identification of priority areas.

Groundwater quality for each Quaternary is expressed as:

- 10^{th} percentile
- 50^{th} percentile (median)
- 95^{th} percentile
- Groundwater quality Reserve (Median +10%) that allows for reasonable contamination.

1.3.7 Sources of data

The following suggested literature sources and databases accessed for groundwater information are listed in Table 1.1.

Table 1-1 Literature sources and databases accessed during this study

Type of Data	Data	Source
Catchment delineation	Quaternary catchment boundaries	WR2012
Groundwater discharge zones	Wetland location	National Freshwater Ecosystem Priority Area (NFEPA) atlas 2011
Population	Population and water source	Stats SA
Climatic data	Rainfall	WR2012
Geology	Lithology and structures	CGS geological maps
Soils	Soil maps	WR2012
Hydrology	Flow data Baseflow	WR2012 GRA II (DWAF, 2006a)
Geohydrology	Harvest Potential Exploitation Potential Recharge Hydrochemistry Water levels Borehole yields	GRA II (DWAF, 2006a) GRA II (DWAF, 2006a) GRA II (DWAF, 2006a) ZQM database NGA NGA
Groundwater use	Licenced groundwater use Municipal water use Schedule 1 water use Livestock water use	WARMS All Towns, Internal Strategic Perspective (ISP) Stats SA GRA II (DWAF, 2006a)
Methodology		GRDM Manual 2012 (Dennis *et al*. 2013)

1.4 PURPOSE OF THIS TASK

This report documents Steps 2 and 3 of the GRDM process, i.e. to describe and prioritise Groundwater Resource Units (GRUs), and quantify the groundwater component of the Reserve.

1.5 PURPOSE OF THIS REPORT

The purpose of this report is to:

- Quantitatively describe the Lower Orange River GRUs.
- Prioritise the GRUs.
- Provide calculations of the groundwater component of the Reserve at a Quaternary or Sub-quaternary level within each GRU.
- Fulfil Task 4 of the TOR: Quantify the groundwater component of the EWR.

1.6 OUTLINE OF THIS REPORT

The report outline is provided below.

Chapter 1: Introduction
This Chapter provides general background to the project, study area and purpose of the report.

Chapter 2: GRDM Approach
The GRDM approach is outlined and discussed.

Chapter 3: Catchment Description
This chapter provides a physical description of the catchment including climate, soils, land cover, population, groundwater use, geology, hydrogeology, aquifer vulnerability and classification, surface groundwater interactions, and a description of the issues relevant to fracking in the study area.

Chapter 4: Description of GRUs
This chapter describes the delineation process and factored considered in the delineation of GRUs and their prioritisation. It also describes each quaternary within each GRU in terms of groundwater use, water quality, recharge, baseflow, groundwater stress and PSC, water levels, groundwater dependency, the groundwater Reserve, its priority, and the allocable groundwater available.

Chapter 5: Prioritised GRUs
This chapter provides a summary of the prioritised quaternaries in each GRU and the critical issues in the catchments.

Chapter 6: References

Chapter 7: Comments Register
Comments from the Client are provided.

2 GRDM APPROACH

The GRDM is embedded in the Integrated steps for the Classification, Reserve and Resource Quality Objectives (RQOs) processes as provided in Figure 2.1.

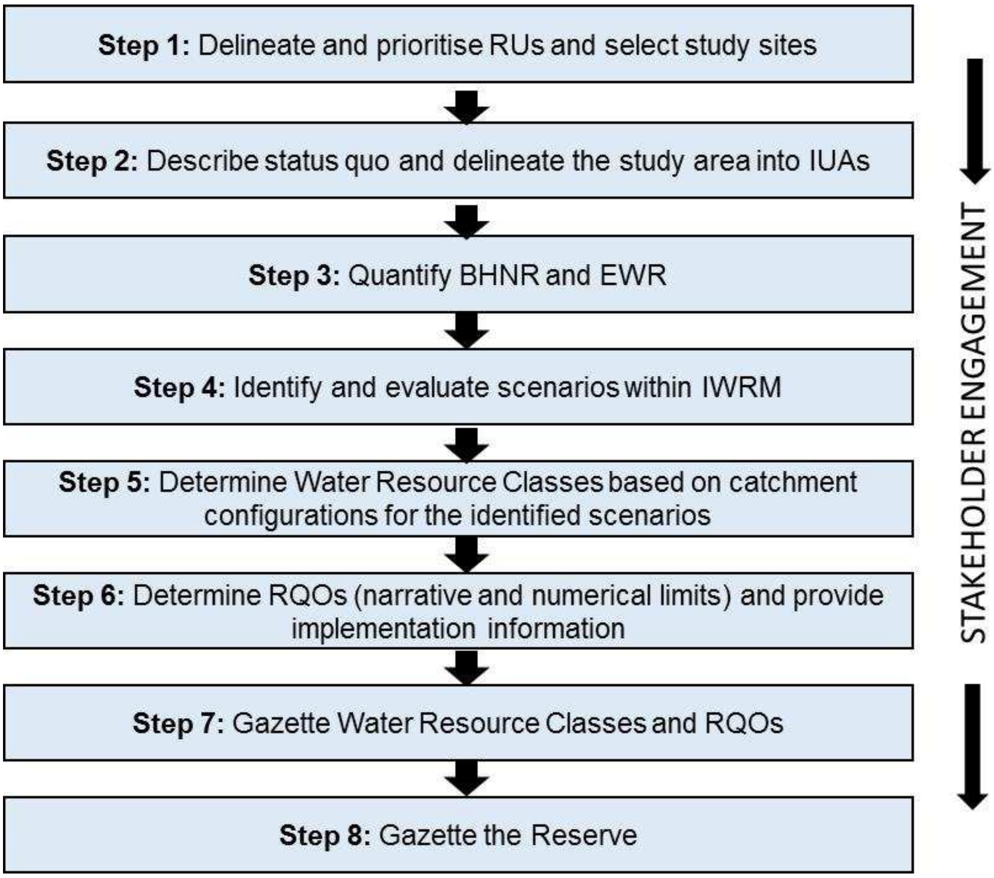


Figure 2.1 Integrated steps for the determination of the Reserve, Classification and RQOs

2.1 STEP 2 DELINEATE AND PRIORITISE IUAs

Objective: The objective of this step is to identify high priority areas. More detailed work for the rest of the steps would focus on these areas. These high priority areas are selected based on ecological, socio-cultural and water resource use importance and are often areas of high ecological importance where water resources are stressed or may be stressed in future.

The bullets below describe the actions required.

- **1. Delineate groundwater RUs (GRUs)**

Delineate, categorise or classify GRUs based on stresses on baseflow from (SFRs and abstraction), and stresses on groundwater levels and groundwater use, such as water levels and groundwater quality, borehole yields, aquifer type, hydraulic boundaries, topography, recharge, aquifer vulnerability, or any factors that warrant differing aquifer management practices.

- **2. Prioritise RUs for groundwater by SFR, stress-index, water level and quality**

Based on Step 1, identify and prioritise GRUs based on stresses. In some areas groundwater stresses which may occur, such as new mines, or groundwater schemes, may not exist yet, and may create future high priority areas.

The concept of stressed water resources is addressed by the NWA, but is not defined quantitatively. The groundwater stress index is used to reflect water availability versus groundwater used. The Stress Index for an assessment area is defined as follows:

Stress Index = Groundwater use/Recharge.

In calculating the Stress Index, the variability of annual recharge is taken into account in the sense that not more than 65% of average annual recharge should be allocated on a catchment scale without caution and monitoring.

After calculating the stress index, the guide presented in Table 2.1 is used to set the present status category of each groundwater unit. Firstly, the stress index is used to check the category assigned using the sustainability indicators i.e. whether an ‘E’ or ‘F’ category is appropriate. The lowest permissible category should be a D, since it is the lowest limit of sustainability.

Table 2-1 Classification of groundwater by stress

Present Class	Description	Present Status Category	Stress Index
I	Minimally used	A	≤0.05
		B	0.05 - 0.2
II	Moderately used	C	0.2 - 0.4
		D	0.4 - 0.65
III	Heavily used	E	0.65 - 0.95
		F	>0.95

2.2 STEP 2: DESCRIBE STATUS QUO

Objective: The objective of this sub-step is to define and describe Groundwater Resources for the purpose of GRU delineation.

Quaternary catchments form the basic unit of delineation. These can be grouped into similar geohydrological properties by aquifer type, or be further subdivided if significant geohydrological features cut through catchments. Areas of similar character are grouped and mapped into distinct units, termed GRUs. Criteria that can be utilised to group or disaggregate catchments to form GRUs include:

- Interaction with other components of the hydrological cycle such as wetlands and rivers.
- Nature of the aquifers (primary, secondary dolomitic, alluvial etc.).
- Groundwater depth.
- Lithology when it affects borehole yields and groundwater quality.
- Topography.
- Groundwater dependence and use.
- Groundwater quality.
- Recharge and available groundwater resources.

For the status quo description, additional data requirements and shortcomings should be identified and stressed regions highlighted. The level of uncertainty associated with the data should be presented. The data should be presented in a manner suitable for GRU and IUA delineation.

The bullets below describe the actions required.

- **1. Describe water resource infrastructure**

This involves identifying hydrogeological units of significance and their boundaries.

- **2. Identify water users and sources**

This involves identifying and describing the main water users and groundwater dependent communities. The process should include towns, industrial, mining and major irrigation users as well as deriving an estimate of Schedule 1 and livestock water users. Water Use Authorisation and Registration Management System (WARMS) data and the All Towns studies are potential sources, but do not include Schedule 1 and smaller users. Census data, verification and validation studies etc. must also be considered. The stress on a GRU should define the level of detail and effort expended in quantifying groundwater use. Streamflow Reduction (SFR) activities also need to be quantified due to their role in baseflow reductions.

- **3. Identify water quality problem areas**

Problematic water quality areas, both in terms of natural constituents that hinder some uses and contamination must be identified. This can be done by listing the percentage or number of samples falling into various water quality categories.

- **4. Define the area of significant resources**

Areas of significant resources that need to be identified include:

  - Areas where groundwater is the sole source of supply.
  - Areas where groundwater contributes a significant component of baseflow and the catchment Mean Annual Runoff (MAR), and where abstraction could reduce these volumes.
  - Areas where large volumes of groundwater exist (based on recharge and the Harvest Potential) and where the existing stress index is low.
  - Areas where groundwater is of good quality.

- **5. Define surface groundwater interaction areas**

Catchments where surface-groundwater interactions exist can be identified from Groundwater Resource Assessment Phase II (GRA II) (DWAF, 2006a). The degree of interaction can be obtained from the Water Resources Simulation Model 2000 (WRSM2000 - the Pitman Model with the Sami or Hughes Model Groundwater interactions) amongst other models, if it is calibrated so that simulated recharge approximates recharge estimates from other methods and baseflows fit observed baseflows. The outcomes required for the above are:

  - Obtaining a groundwater balance of rainfall recharge and transmission losses from rivers to discharge as baseflow, abstraction, and evapotranspiration under natural and present conditions.
  - Quantifying the volumetric contribution of baseflow to rivers.
  - Quantifying the degree to which SFR and abstraction have reduced baseflow, and to which abstraction impacts on baseflow.
  - Observed gauging weir data to calibrate baseflow volumes and cumulative frequency or flow duration curves.

- **6. Describe the groundwater quantity and quality status quo**

The information obtained is utilised to define GRUs and describe the existing status quo of each identified GRU.

2.3 STEP 3 CLASSIFY BHNR

The Basic Human Needs component of the Reserve (BHNR) is set by the Water Services Act (Act No. 108 of 1997) at 25 l/p/d. The definition of the Reserve refers to people who are now or who will - in the reasonably near future - be reliant on a resource for water. The BHN component of the Reserve is readily calculated by multiplying the number of people living within the confines of a resource unit AND WITHOUT A CURRENT FORMAL SOURCE OF WATER SUPPLY by 25 l/d.

Where a large proportion of the population already has access to a formal regional water system, setting aside a BHN for this portion and adding it to existing lawful groundwater use would result in a double accounting of water allocations. Hence this study took the approach of only calculating a BHN for the population without access to a formal regional water supply. However, since the bulk of users included in the Reserve are Schedule 1 users, a per capita consumption of 200 l/c/d was utilised.

For the groundwater component of the Reserve, the objective is to define, in a quantitative manner, the groundwater contribution to baseflow, which is required to calculate the groundwater component of the Reserve, and its contribution to the EWR.

The bullets below describe the actions required.

- **1. Calculate natural baseflow**

This step is necessary to determine the impact of current land use and abstraction in Step 2. . .

- **2. Generate present day base flow contribution base flow reduction, stress-index**

Present day and natural baseflow are required, based on a model calibrated against a baseflow time series and recharge, to quantify stress. This allows the quantification of SFRs and groundwater abstraction on baseflow and the importance of groundwater to the EWRs.

- **3. Align with EWR (base flow) to calculate groundwater component of the Reserve (and derive allocable groundwater)**

Present baseflows compared to the EWR provide a measure of how much further abstraction can be sustained before baseflows reach the EWR at various points in the study area. In some cases, the EWR may preclude the abstraction of available groundwater resources. This then follows that this action depends on the EWR determination and therefore the linked arrow from EWR to groundwater.

To quantify the groundwater component of the Reserve for each groundwater resource unit, the groundwater volume that is required to sustain the BHN and aquatic ecosystems (EWR) is required. Only once the groundwater component of the Reserve has been established, can further groundwater allocations be implemented.

The groundwater component of the Reserve for each GRU is calculated by:

Reserve = (EWR_{gw} + BHN_{gw})

Where:
BHN_{gw} = basic human needs derived from groundwater
EWR_{gw} = groundwater contribution to EWR

Groundwater contributions for the EWR include:

- Baseflow to rivers and springs, including high lying springs fed by interflow.
- Seepage to wetlands and groundwater dependent ecosystems.

The allocatable groundwater is the difference between recharge and the Reserve. The Groundwater allocation also has to take into account international obligations, existing Schedule 1 usage, General Authorizations and Existing Lawful Users before new license applications can be consideredDue to the variability of recharge in arid and semi-arid areas, allocable groundwater should not exceed 65% of recharge.

2.4 STEP 4: IDENTIFY AND EVALUATE SCENARIOS WITHIN INTEGRATED WATER RESOURCE MANAGEMENT

There are no specific groundwater tasks involved, unless scenarios of differing groundwater abstraction can have an impact on the EWR.

2.5 STEP 5: DETERMINE WATER RESOURCE CLASSES BASED ON SCENARIOS

No specific groundwater tasks.

3 CATCHMENT DESCRIPTION

3.1 STUDY AREA

As indicated in the TOR, the study area is the Lower Orange River WMA (WMA) previous WMA 14). It is the largest WMA in the country, and covers most of the Northern Cape Province, as shown in the locality map in Figure 3.1. The geographic extent of the Lower Orange WMA largely corresponds to that of the Northern Cape Province. The Lower Orange River WMA is situated in the western extremity of South Africa and borders on Botswana, Namibia and the Atlantic Ocean.

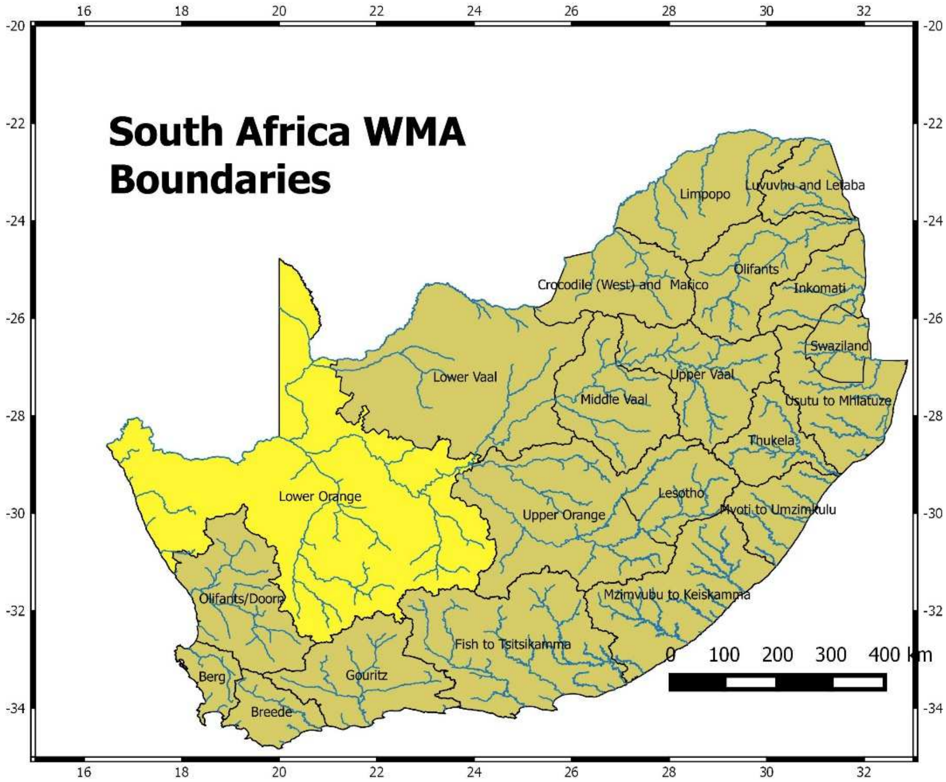


Figure 3.1 Location of Lower Orange WMA

This core area forms part of the Orange-Senqu River Basin, which straddles four International Basin States, i.e. Lesotho (Senqu River originating in the highlands), Botswana in the Northeastern part of the Basin, the Fish River in Namibia and the largest area situated in South Africa. The focus area of the study comprises only the South African portion of the Lower Orange River Catchment. The Eastern Boundary starts where the Vaal River enters the Orange River, and the Western Boundary is the Atlantic Ocean. The study area is downstream of the Upper Orange, Senqu, and the Integrated Vaal River System and as such, affected by the upstream activities in the highly developed river basin. The Orange River forms the border between the Republic of South Africa (RSA) and Namibia to the west of 20 degrees longitude over a distance of approximately 550 km.

The study area is mostly arid with mean Quaternary catchment rainfall varying from 400 mm in the east to 50 mm on the west coast. The topography of the area is generally flat and includes large pans or endoreic areas that do not contribute to runoff reaching the main Orange River. The exceptions are the Karoo escarpment zone in the south, and the Namaqualand hills.

The Vaal River is the main tributary to the Lower Orange River with other tributaries including the Ongers and Hartebeest rivers from the south, and the Molopo River and Fish River (Namibia) from the north. There are a number of highly intermittent watercourses along the coast, which drain directly to the ocean, with the Buffels, Swartlintjes and Swartdoorn being the most significant of these.

The Orange River is an international resource, shared by four countries i.e. Lesotho, South Africa, Botswana and Namibia – this study will only focus on South African role players. Numerous Local Municipalities are located in the Lower Orange WMA (Figure 3.2).

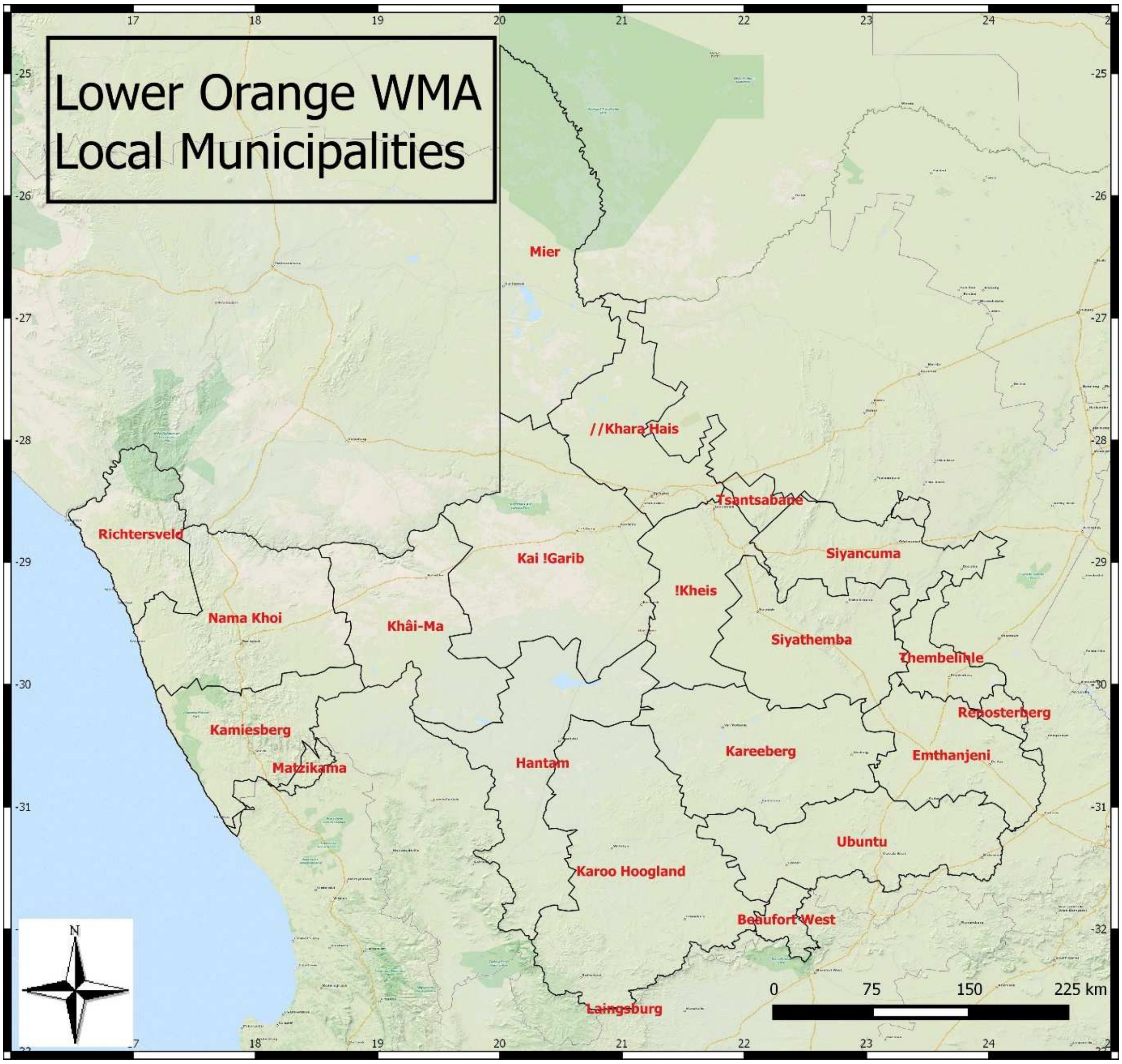


Figure 3.2 Local Municipalities in the Lower Orange WMA

3.2 PHYSIOGRAPHY

The WMA can be divided into three sub areas:

- The Orange sub-area, which includes the Orange River over the whole of its length through the water management area, together with minor tributary streams.
- The Orange Tributaries sub-area, comprising the catchments of the Ongers and Hartebeest Rivers.
- The Orange Coastal sub-area, which includes the mostly dry watercourses that lead directly to the ocean.

The Orange Tributaries subarea is bounded by the Karoo Escarpment, which forms the southern margin of the WMA at an altitude of 2000 metres above mean sea level (mamsl) (Figure 3.3). The land slopes northwards towards the Orange River, to below 1000 m. The Orange subarea slopes westward towards the Atlantic Ocean.

The Orange Coastal zone is bounded by a range of hills in Namaqualand rising to 500 mamsl, which forms a divide between catchments draining to the Orange, and catchments draining westwards to the Atlantic Ocean.

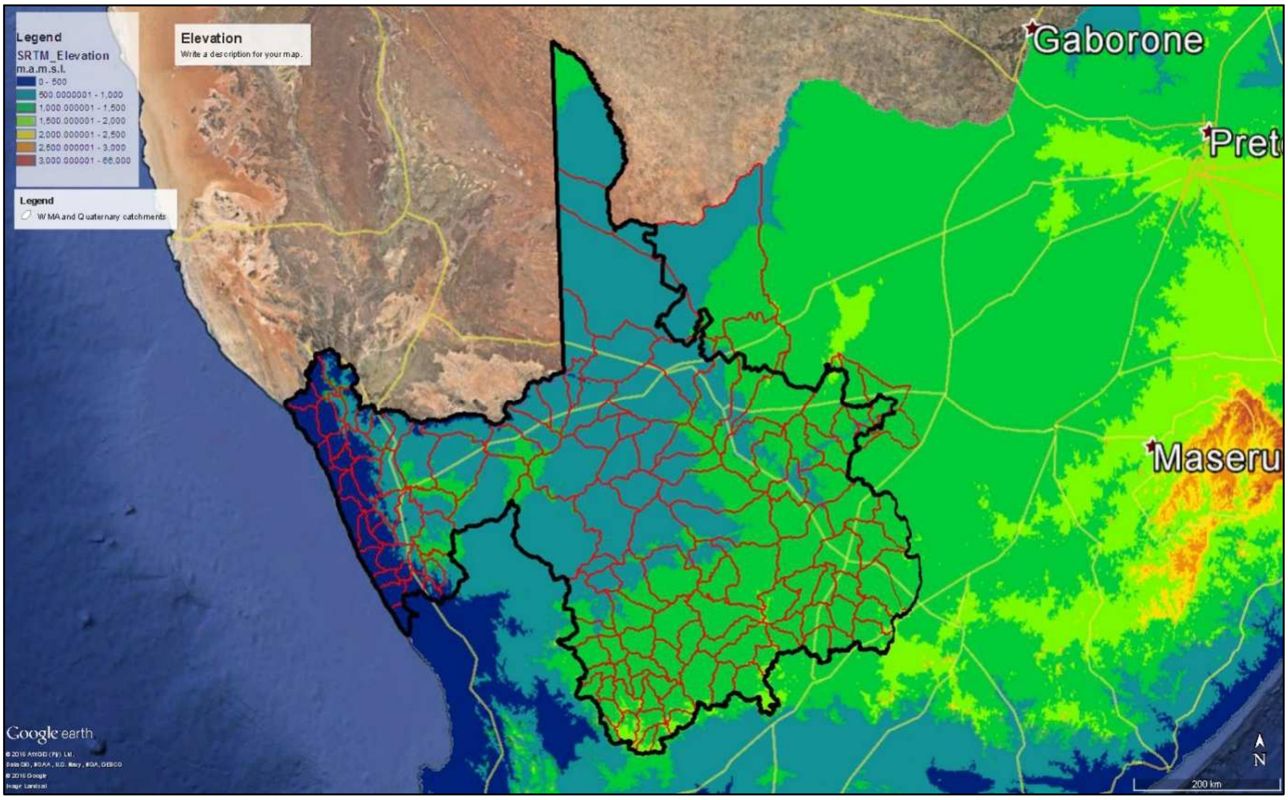


Figure 3.3 Physiography of the Lower Orange WMA

3.3 SURFACE WATER AND DRAINAGE

The Lower Orange WMA encompasses a total catchment area of 252 070 km^2. The primary and secondary rivers of the WMA are shown in Figure 3.4. The WMA encompasses secondary drainage regions D4, D5, D6, D7, D8, F1, F2, F3, F4, F5 and portions of C5, C9, D3 and, F6 (Figure 3.4).

With the exception of sparse and highly intermittent runoff from local tributaries and occasional inflows from the Fish River in Namibia, the Lower Orange WMA is totally dependent on flow in the Orange River generated from upstream WMAs.

Surface water resources in the water management area are fully developed. Owing to the fact that water has to travel a distance of 1 400 km from the point of release at Vanderkloof Dam to the most downstream point of use, large operational and transmission losses are incurred in the process of ensuring that the requirements of users are met.

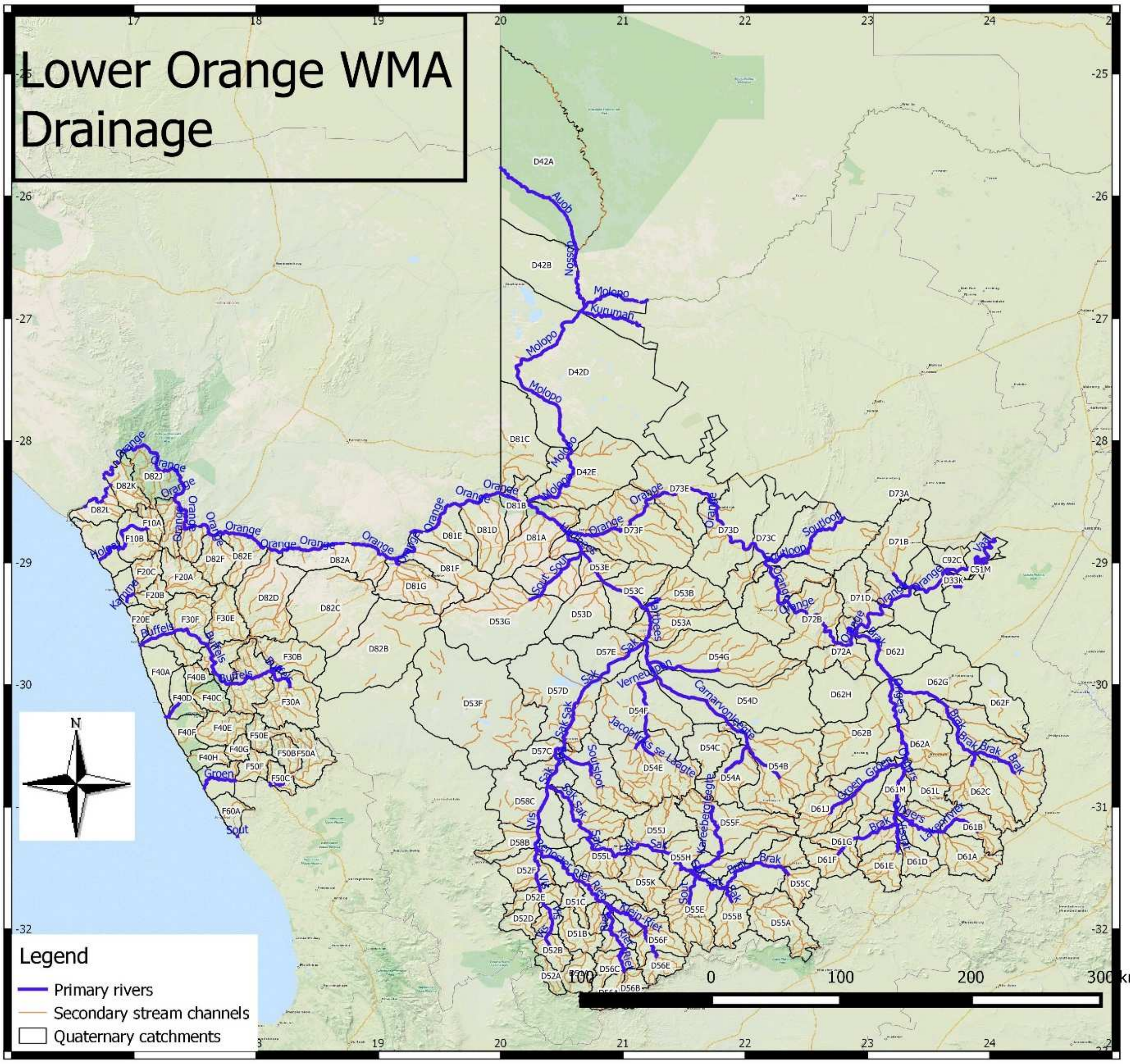


Figure 3.4 Drainage network of the Lower Orange WMA

The WMA is characterised by several north or south flowing rivers oriented towards the Orange, the westerly flowing Orange River, and the western coastal rivers flowing towards the sea. The major rivers are the:

- **Orange River:** The Orange River enters the WMA in D33K. The Vaal River enters the WMA in C92B near Douglas and joins the Orange to begin the D7 drainage region. The Orange subsequently directly drains the D7 and D8 catchments.
- **Molopo River:** This River drains the D4 catchments and flows into the Orange River in D81; however, it rarely contributes water to the Orange, with most of the flows lost as evaporation or into the Kalahari sands.
- **Brak/Ongers:** This river system drains northwards to the Orange upstream of Prieska and drains D61 and D62.
- **Hartbees:** The Hartbees system drains northward to the Orange and drains the D5 catchments.
- **Coastal Rivers:** These catchments consist of a series of intermittent rivers that drain westward directly to the sea.

3.4 CLIMATE

3.4.1 Climate type

The climate is classified as Desert Climates (B) under the Koeppen-Geiger classification Low-Latitude Deserts (Bwh and Bwk) (Figure 3.5). The third letter indicates temperature. The h signifies low-latitude climate (average annual temperature above 18 C) while *k* signifies middle-latitude climate (average annual temperature below 18°C). The delineation between the Bwh and Bwk region approximates 1500 mamsl elevation.

This climatic region covers the Kalahari, and coincides with the equatorward edge of the subtropical high-pressure belt and trade winds. Air flows generally downward so air masses that cause rain rarely penetrate the area. There is a general lack of precipitation with no pattern developed.

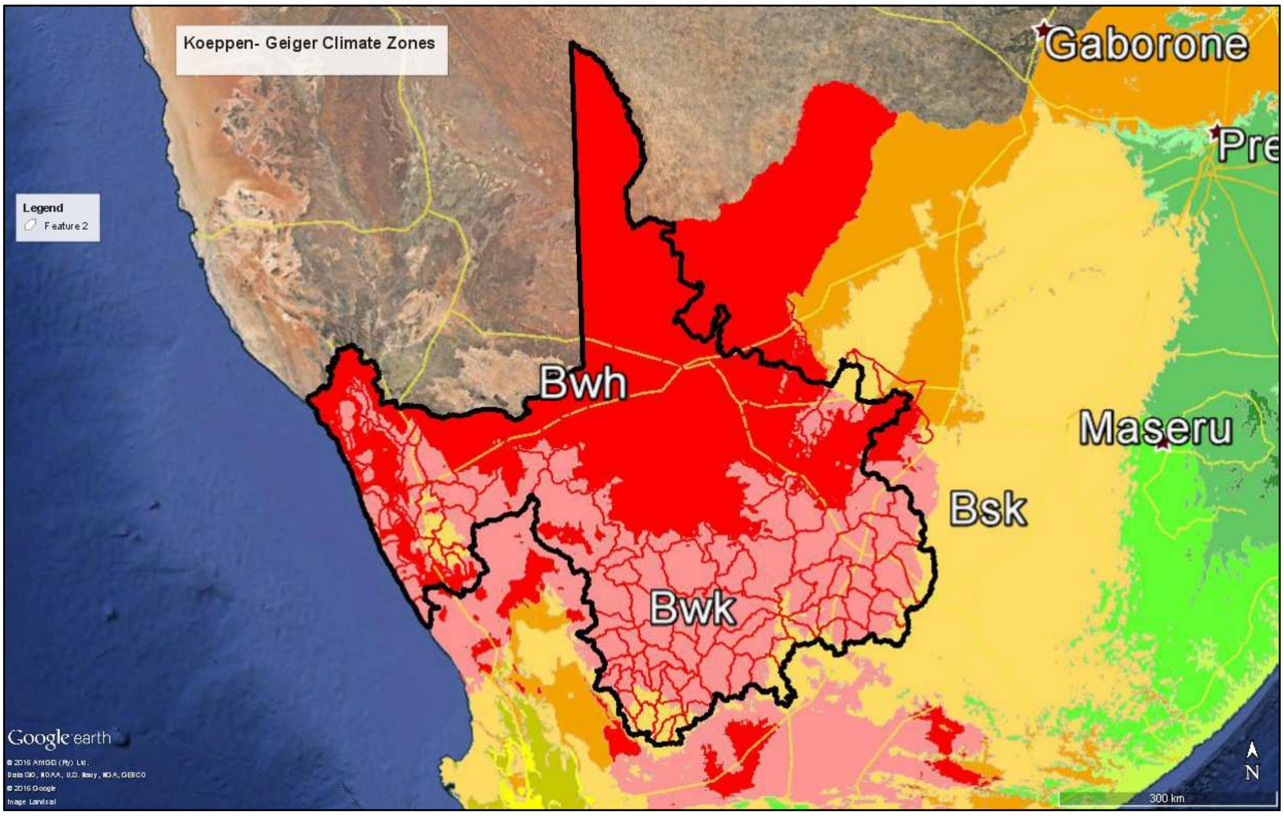


Figure 3.5 Koeppen – Geiger Climatic classification of the Lower Orange WMA

3.4.2 Rainfall

Gridded rainfall shows that rainfall ranges from a high of 400 millimetres per annum (mm/a) in the east, declining westward to a low of 20 mm/a near the mouth of the Orange River (Figure 3.6), and is characterised by prolonged droughts. Rainfall towards the upper range occurs in the highlands around Sutherland at the southwest margin of the Escarpment region, and near Kheis in the mountainous region of Namaqualand.

Figure 3.7 shows the Mean Annual Precipitation (MAP) distribution by catchment. Catchment MAP varies from 29 mm/a in the Namib Desert, where the Orange River enters the Atlantic Ocean, to 331 mm/a in the east near Douglas and Postmasburg.

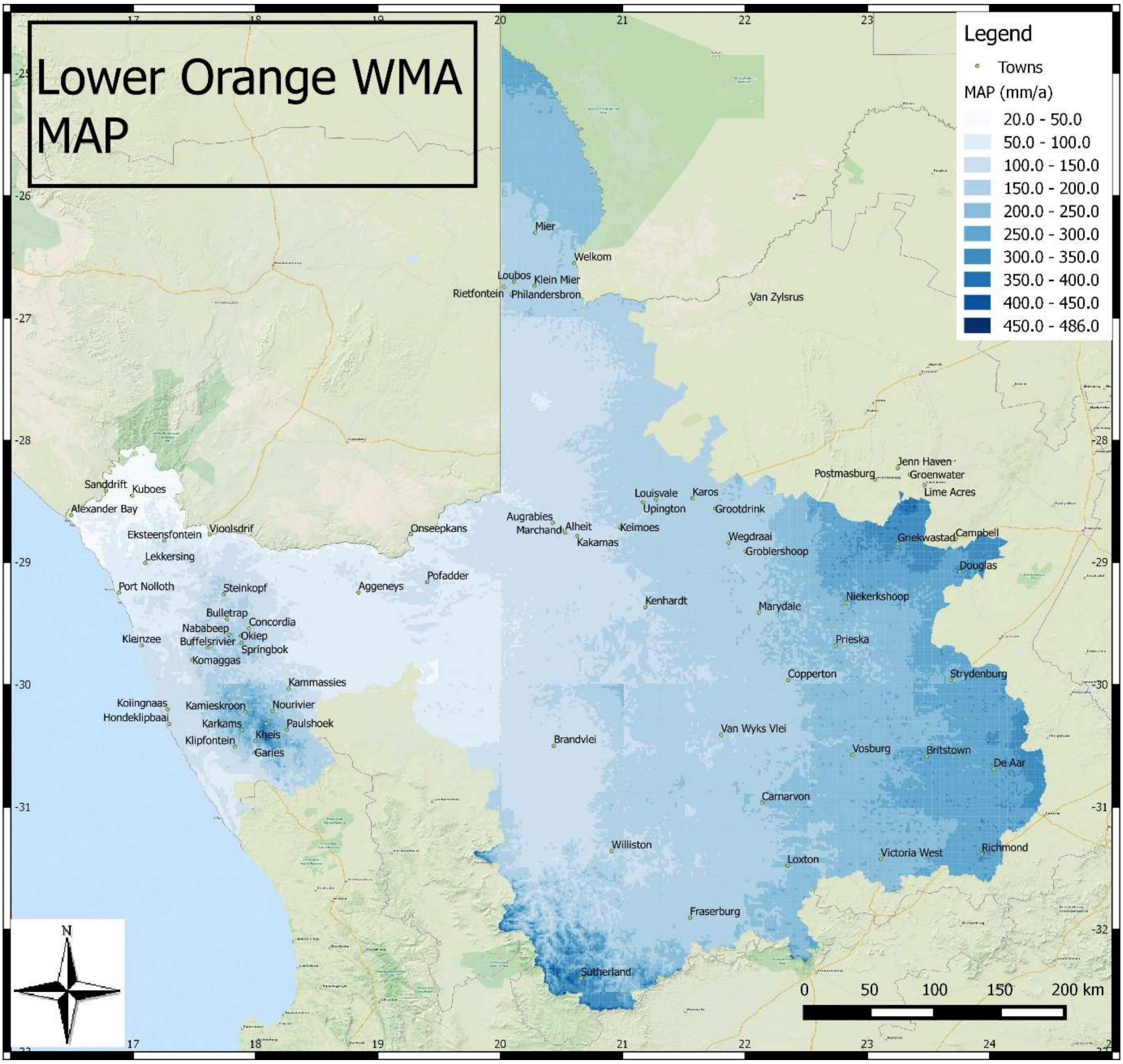


Figure 3.6 MAP of the Lower Orange WMA

3.4.3 Evaporation

S-pan evaporation decreases towards the coast and southwards from a high of over 2600 mm/a in the north to 1700 mm/a on the west coast and 1800 mm/a near Sutherland (Figure 3.8).

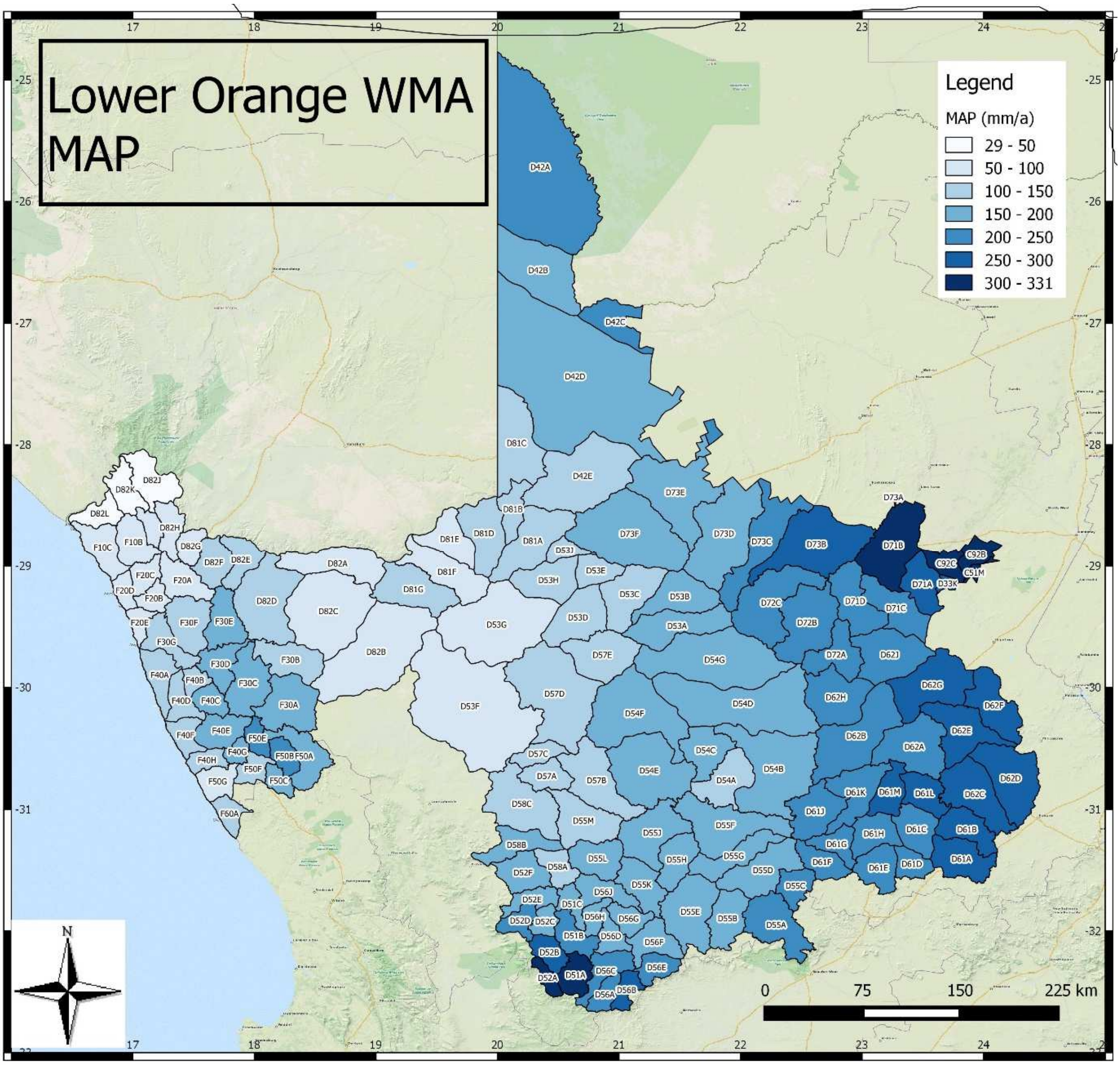


Figure 3.7 Catchment MAP of the Lower Orange WMA

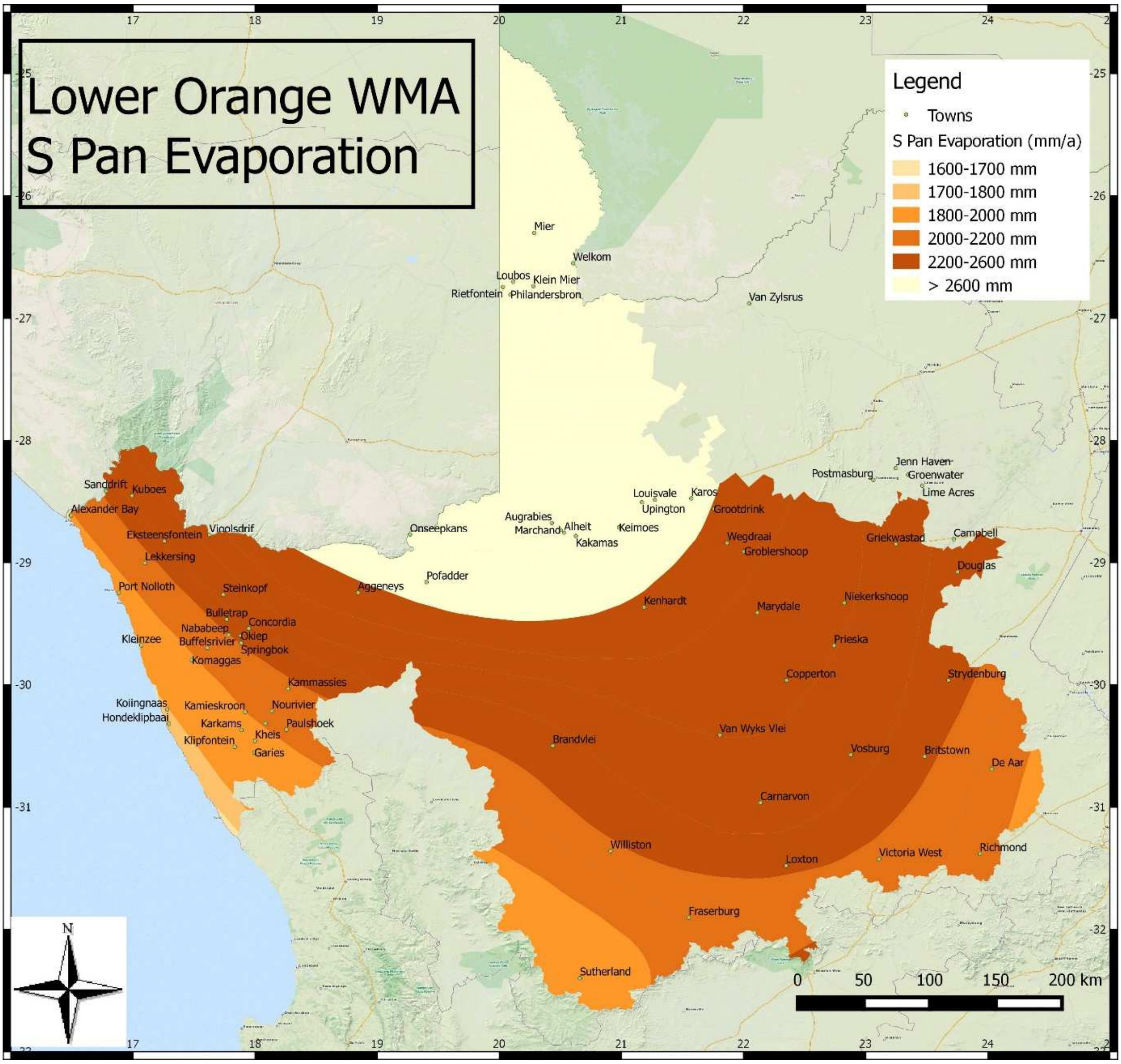


Figure 3.8 S pan evaporation of the Lower Orange WMA

3.5 VEGETATION

The Lower Orange WMA is characterised by various veld types, which are depicted in Figure 3.9. The main vegetation types found in the WMA are:

- **Bushmanland** vegetation covering the central portion of the bioregion and consists of Karroid shrubland and Kalahari grassland.
- **Eastern Kalahari Bushveld** comprising bushveld, thornveld and shrubland, and is found in the east from Douglas to Gorblershoop.
- **Gariep desert** consisting of mountain, sheetwash and plains desert and found in the low rainfall strip of the Lower Orange River.
- **Inland Saline** vegetation consisting of southern Kalahari, Bushmanland, Highveld and Namaqualand saltpans.
- **Kalahari Duneveld** and bushveld found in the northern region of the Kalahari panhandle.
- **Karoo Renosterveld** found on dolerites and shales of the Escarpment region southwest of Sutherland.
- **Namaqualand Cape Shrublands** consisting of Renosterveld and Fynbos is found in patches in southern Namaqualand.

- **Namaqualand Hardeveld** consisting of Hardeveld and Blomveld covers large parts of Namaqualand.
- **Namaqualand Sandveld** consisting Duneveld and sandy grassland covers the bulk of the coast of Namaqualand.
- **Northwestern Fynbos** found in patches in coastal Namaqualand.
- **Richtersveld** consisting of succulents and shrubs cover the northwest corner of the WMA.
- **Southern Namib Desert** occupying the border region of the Orange River bordering Namibia.
- **Trans-escarpment Succulent Karoo** vegetation found in the south of the WMA in the escarpment region north of Sutherland.
- **Upper Karoo** vegetation covering the southern region of the WMA, which gives way to Bushmanland vegetation to the north as the MAP decreases.

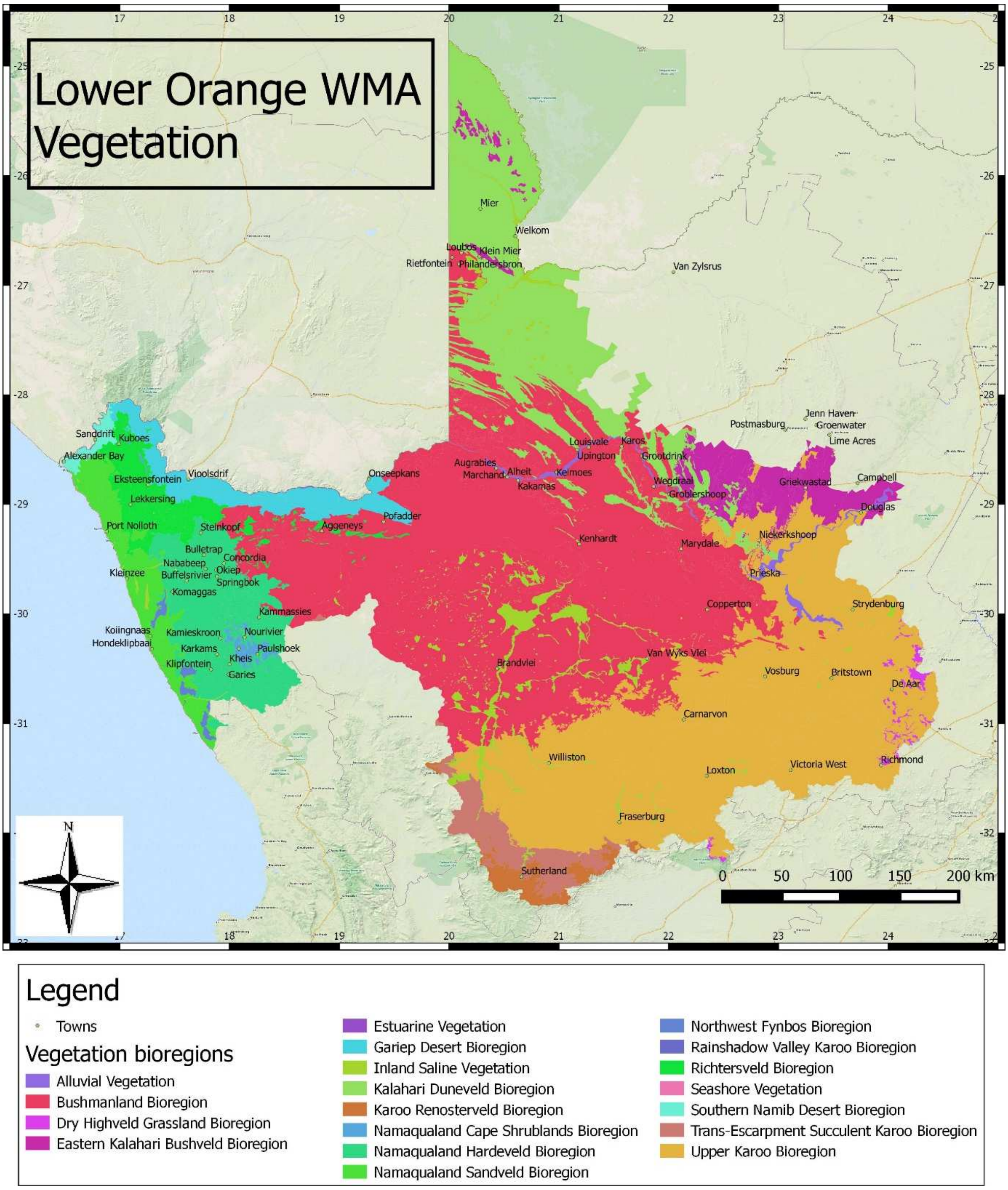


Figure 3.9 Vegetation bioregions of the Lower Orange WMA

3.6 SOILS

Soil cover is an important consideration for groundwater recharge and aquifer vulnerability to contamination. The majority of the WMA is covered by soils with minimal development, which are usually shallow and established on hard rock. These consist of:

- **Leptosols:** Soils which are *either* limited in depth by continuous hard rock within 25 cm from the soil surface, *or* overly material with a calcium carbonate equivalent of more than 40% within 25 cm from the soil surface, *or* contain less than 10% (by weight) fine earth (mineral soil material with a diameter of 2 mm or less) to a depth of 75 cm from the soil surface.
- **Regosols:** Soils where soil has been eroded to the extent that the underlying unconsolidated material comes near to the surface, or where soil formation has not played an important role, e.g. in desert regions.
- **Calcisols:** Soils where carbonate-rich groundwater comes near the surface resulting in soils having a calcic horizon from the accumulation of secondary calcium carbonates.
- **Durisols:** Soils develop where a source of silica is present and having a hardpan horizon from the accumulation of secondary silica within 100 cm from the soil surface.

The Kalahari region and the west coast are underlain by:

- **Arenosols:** Generally of a loamy sand or coarser texture with a depth of at least 100 cm from the soil surface. They contain less than 35% (by volume) rock fragments or other coarse fragments within 100 cm from the soil surface.

The margins of the Kalahari and the eastern part of the Karoo are underlain by:

- **Lixisols:** Soils with a high base status of Ca, Mg, K and Na with respect to the cation exchange capacity partly due to less leaching, and partly to admixture from airborne dust from adjacent desert regions. They have a subsurface horizon with distinct higher clay content than the overlying horizon.
- **Cambisols:** Have a cambic horizon (a horizon showing evidence of alteration with respect to the underlying material), or a mollic horizon overlying a subsoil, which has a base saturation of less than 50% in some part within 100 cm from the soil surface.
- **Luvisols:** Soils with a clay rich B-horizon with a high base status.

From Loxton to Richmond, soils are found with a marked accumulation of clay in the B-horizon.

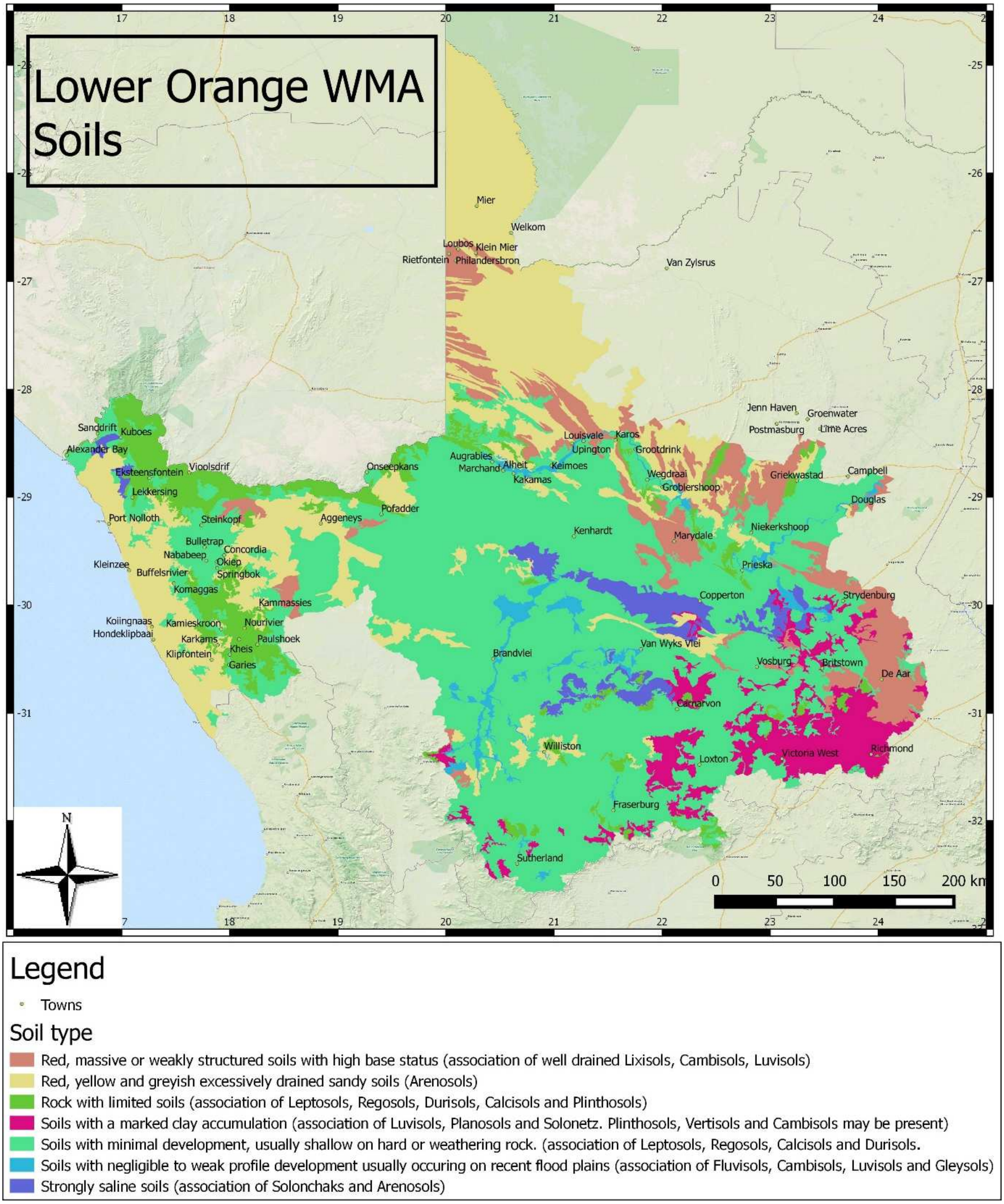


Figure 3.10 Soil types of the Lower Orange WMA

3.7 LAND COVER

The Lower Orange WMA largely consists of low shrubland and is largely undeveloped (rural land use). Grasslands exist in the Kalahari panhandle and the lower Orange from Aggeneys to Sanddrift (Figure 3.11).

Important conservation areas in the WMA include the Kgalagadi Transborder National Park, the Augrabies National Park, the Richtersveld National Park and a transboundary Ramsar wetland site at the Orange River mouth.

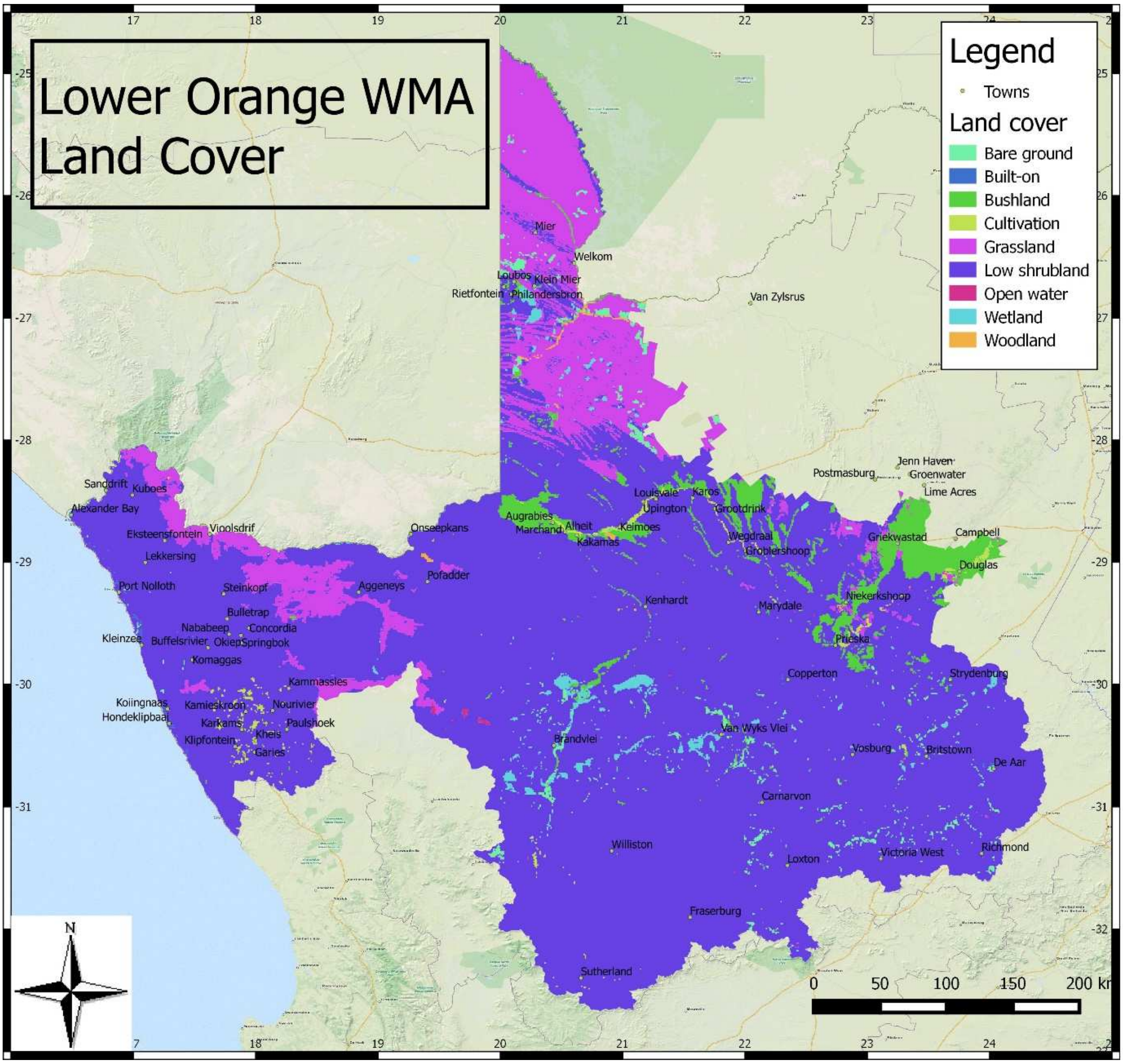


Figure 3.11 Land cover of the Lower Orange WMA

3.8 POPULATION

According to the 2011 Census, 419 413 people inhabit the WMA. The bulk of the population live near the Orange River, with population densities on a Quaternary scale ranging from 0.4 - 40 people per km^2 (Figure 3.12). Large areas of the Karoo and west coast are sparsely populated (<0.2 people per km^2).

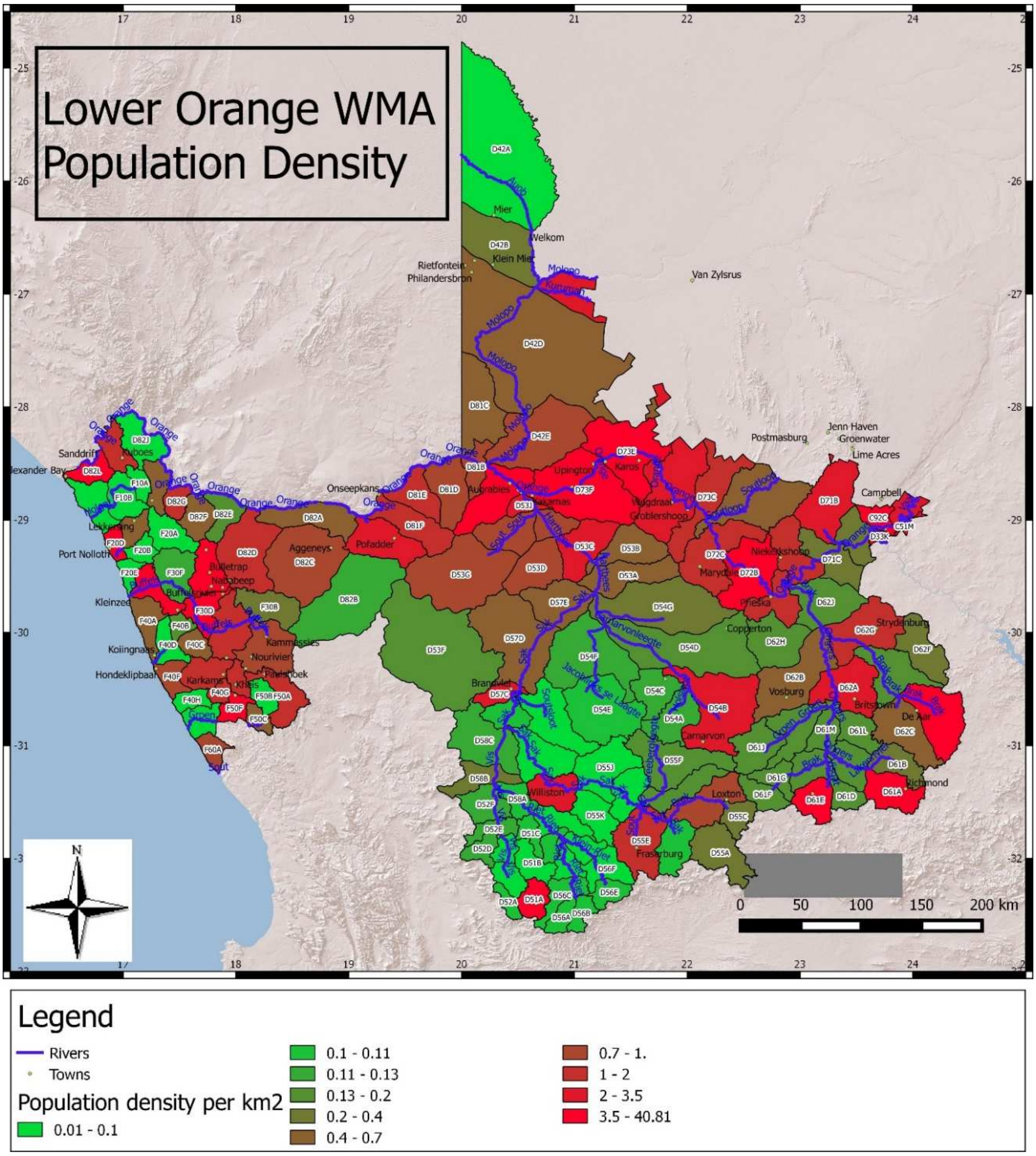


Figure 3.12 Population density of the Lower Orange WMA

3.9 GROUNDWATER USE

3.9.1 Domestic use

Many communities within the WMA are dependent on groundwater for municipal supply. These towns are shown in Figure 3.13 and Table 3.1. Data on groundwater use was collected from the All Towns strategy reports, and the Lower Orange ISP. Where no data was available from the All Towns studies, the ISP data was used. The population within the WMA supplied by formal groundwater schemes utilises 11.015 Mm^3/a (Table 3.2).

In addition to formal groundwater supply, a large segment of the population is dependent on boreholes and springs. These users were considered Schedule 1 domestic groundwater users. The Schedule 1 use was calculated by taking the number of households stating they obtain water from boreholes or springs, but is not on a regional water scheme and multiplying by 200 Litres per capita per day (l/c/d) (Table 3.2).

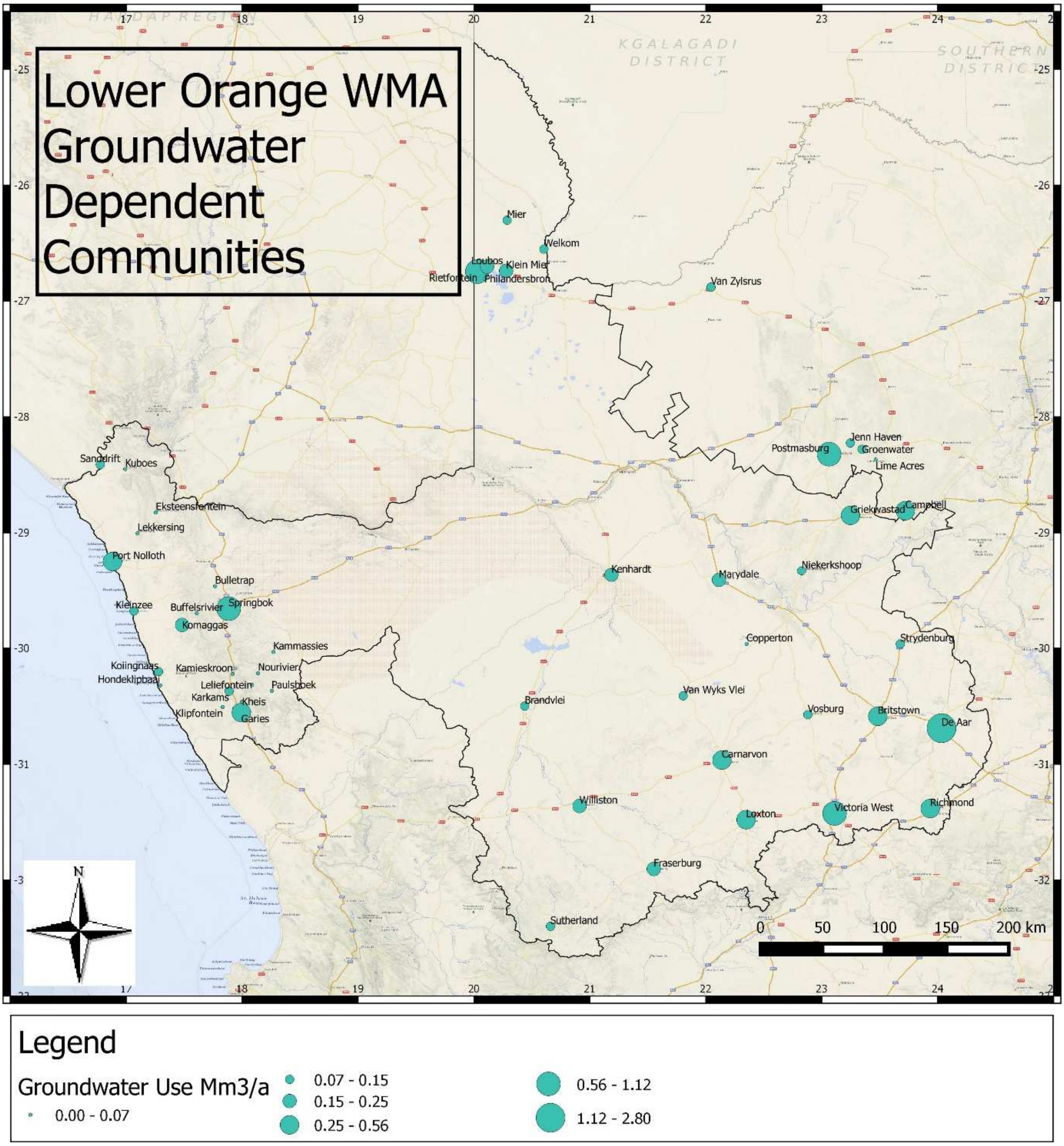


Figure 3.13 Groundwater dependent communities in the Lower Orange WMA

The total domestic use is the population on regional water schemes and Schedule 1. The Groundwater dependent population is the population obtaining water from Schedule 1 boreholes and springs, or from regional groundwater schemes (Figure 3.14). Except for catchments through which the Orange flows, or is adjacent, the bulk of the region is dependent on groundwater for domestic water supply.

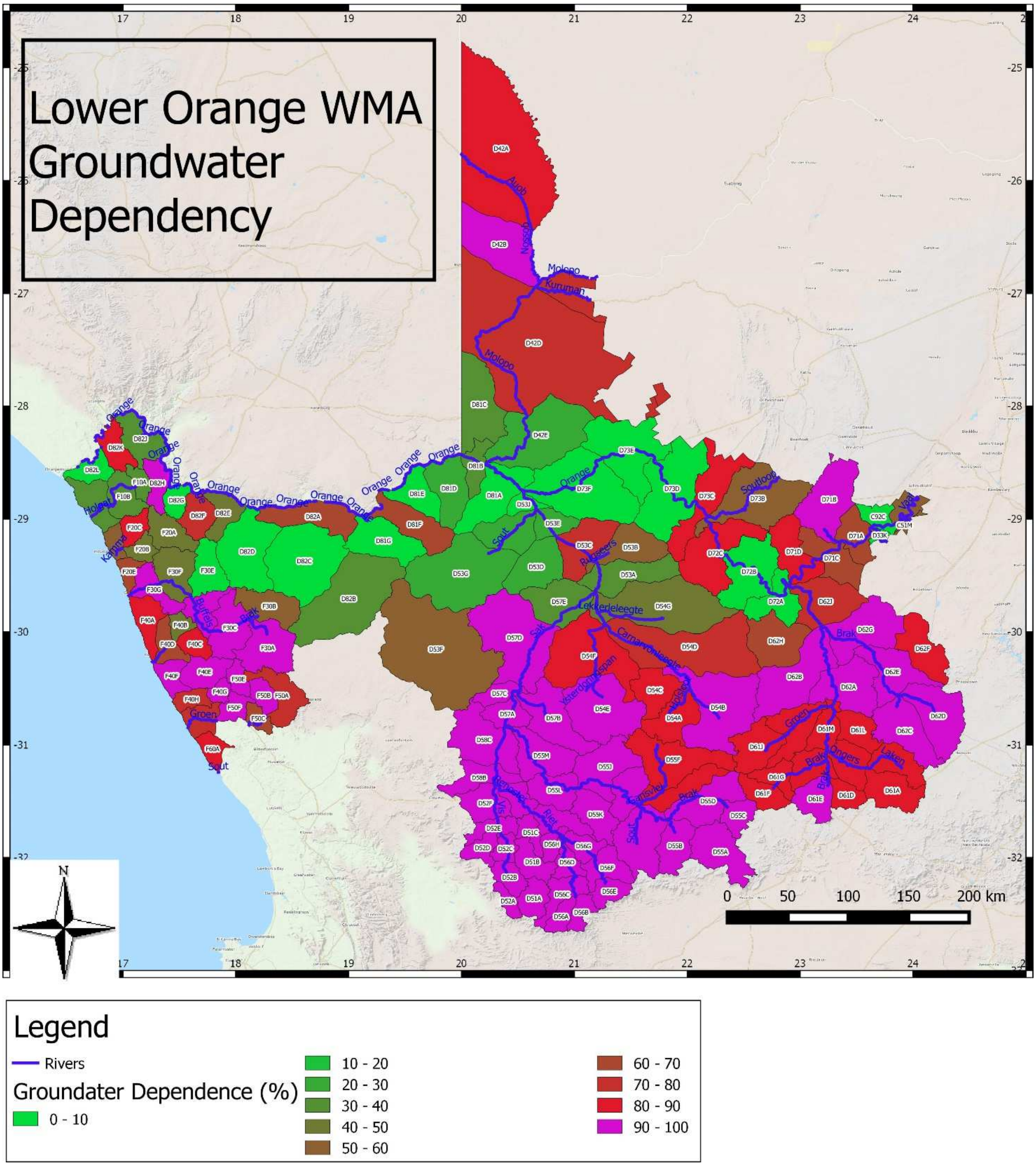


Figure 3.14 Groundwater dependency in the Lower Orange WMA

Table 3-1 Towns in the Lower Orange WMA, dependent on groundwater

Town	Source	Use estimate	All Towns		ISP			Assumed Use
		Confidence	Mm^3/a	l/c/d	m^3/d	l/c/d	Mm^3/a	Mm^3/a
Campbell	3 Bore Holes (BH)	Medium	0.473	780	50	30	0.01825	0.473
Lime Acres	BH and Vaal Gamagara pipeline	Medium		0		0	0	0
Mier LM Combined Clusters Groot Meir	BH	Low	0.15	492	35	42	0.012775	0.15
Klein Mier	BH	Low		0	52	81	0.01898	0.01898
Welkom	BH	Low		0	34	56	0.01241	0.01241
Van Zylsrust	5 BH	Low-Medium	0.132	273		0		0.132
Loubos					50		0.01825	0.01825
Rietfontein	BH	Low		0	215	84	0.078475	0.078475
Philandersbron					110		0.04015	0.04015
Riemvasmaak	2 BH and Orange River	Low		0		0	0	0
Sutherland	3 BH	Low	0.15	226	366	201	0.13359	0.15
Kenhardt	9 BH and Orange River	High	0.248	168	600	148	0.219	0.248
Carnarvon	8 BH	Medium	0.485	256	900	174	0.3285	0.485
Vanwyksvlei	3 well fields	Medium	0.1	119	424	183	0.15476	0.1
Loxton	7 BH	Medium	0.445	1908	180	282	0.0657	0.445
Fraserburg	5 BH	Low		0	527	220	0.192355	0.192355
Williston	3 BH	Medium	0.221	204	555	187	0.202575	0.221
Brandvlei	5BH	Medium	0.137	134	245	87	0.089425	0.137
Richmond	6 BH	Medium	0.564	432	713	199	0.260245	0.564
Victoria West	11 BH	Medium	0.722	296	1457	218	0.531805	0.722
Britstown	10 BH	High	0.349	205	1000	215	0.365	0.349
Vosburg	3 BH	Low	0.146	355	91	81	0.033215	0.146
De Aar	51 BH	Medium	2.798	290	8900	337	3.2485	2.798
Strydenburg	5 BH	Medium	0.146	157	220	87	0.0803	0.146
Griekwastad	3 BH	Medium	0.5	244	515	92	0.187975	0.5

Town	Source	Use estimate	All Towns		ISP			Assumed Use
		Confidence	Mm^3/a	l/c/d	m^3/d	l/c/d	Mm^3/a	Mm^3/a
Niekerkshoop	5 BH	Medium	0.148	251	282	175	0.10293	0.148
Marydale	6 BH and 1 Well	Medium	0.245	349	238	124	0.08687	0.245
Groenwater					42		0.01533	0.01533
Jenn Haven					28		0.01022	0.01022
Postmasburg	12 BH	Medium	1.12	122		0	0	1.12
Onseepkans	Orange River, however they have a registration for boreholes	Medium		0		0	0	0
Pofadder	Orange River however they have a registration for boreholes	Medium		0	0	0	0	0
Eksteenfontein	4 BH	Low		0	42	83	0.01533	0.01533
Khubus					177		0.064605	0.064605
Sanddrift	2 BH	Low	0.14	158		0	0	
Lekkersing					56		0.02044	0.02044
Port Nolloth	3 BH	Medium	0.409	149		0	0	0.409
Kammassies					52		0.01898	0.01898
Leliefontein	2 BH	Low	0.026	22	51	16	0.018615	0.026
Nourivier					30		0.01095	0.01095
Kamieskroon	3 BH	Low	0.16	135	94	29	0.03431	0.16
Buffelsrivier					96		0.03504	0.03504
Bulletrap					60		0.0219	0.0219
Kleinsee	Fellman Well	Low		0	250	91	0.09125	0.09125
Komaggas	2 fields	Low		0	467	124	0.170455	0.170455
Koingnaas					211		0.077015	0.077015
Karkhams					251		0.091615	0.091615
Hondeklip	BH	Low		0	183	56	0.066795	0.066795
Klipfontein					7		0.002555	0.002555
Paulshoek					16		0.00584	0.00584

Town	Source	Use estimate	All Towns		ISP			Assumed Use
		Confidence	Mm³/a	l/c/d	m³/d	l/c/d	Mm³/a	Mm³/a
Kheis					25		0.009125	0.009125
Garies	4 BH	Low	0.348	294	250	77	0.09125	0.348
Springbok	Orange River, however they also have registered boreholes						0.851	0.851
TOTAL								**12.16107**

Table 3-2 Groundwater use by catchment in the Lower Orange WMA

Scheme	GRA II		WARMS 2016 (Mm³/a)				Census 2011	All Towns and ISP (Mm³/a)	Total Use (Mm³/a)	Domestic Us (Mm³/a)e	Population	Groundwater Dependent Population	l/c/d
	Livestock (Mm³/a)	Livestock (m³/a/ha)	Municipal	Irrigation	Mining	Industry	Schedule1 (Mm³/a)						
C51M	0.019	0.12	0.000	0.000	0.000	0.000	0.026		0.044	0.026	648	350	200
C92B	0.092	0.47	0.000	0.042	0.000	0.000	0.082		0.215	0.082	2159	1116	200
C92C	0.046	0.24	0.000	0.291	0.001	0.000	0.114	0.473	0.925	0.587	25336	1566	1027
D33K	0.016	0.32	0.000	0.000	0.000	0.000	0.007		0.023	0.007	1334	101	200
D42A	0.023	0.02	0.150	0.000	0.000	0.000	0.022	0.150	0.194	0.172	454	384	1223
D42B	0.081	0.25	0.022	0.000	0.000	0.007	0.024	0.031	0.143	0.055	1272	1170	128
D42C	0.221	0.12	0.012	0.002	0.000	0.000	0.141	0.132	0.496	0.273	4580	3317	225
D42D	0.397	0.24	0.000	0.005	0.384	0.000	0.119	0.137	1.041	0.256	7150	5428	129
D42E	0.157	0.37	0.000	0.000	0.000	0.000	0.061		0.218	0.061	3014	831	200
D51A	0.028	0.35	0.000	0.818	0.000	0.130	0.012	0.150	1.138	0.162	2917	2906	152
D51B	0.031	0.35	0.000	0.443	0.000	0.000	0.006		0.480	0.006	91	84	200
D51C	0.008	0.15	0.000	0.000	0.000	0.000	0.004		0.012	0.004	55	51	200
D52A	0.013	0.35	0.000	0.266	0.000	0.000	0.003		0.282	0.003	40	37	200
D52B	0.023	0.35	0.000	0.428	0.000	0.000	0.004		0.455	0.005	67	62	200
D52C	0.017	0.36	0.000	0.447	0.000	0.000	0.003		0.467	0.003	49	45	200
D52D	0.004	0.06	0.000	0.076	0.000	0.000	0.005		0.085	0.005	75	69	200
D52E	0.002	0.03	0.000	0.279	0.000	0.000	0.004		0.286	0.005	71	65	200

Scheme	GRA II		WARMS 2016 (Mm^3/a)				Census 2011	All Towns and ISP (Mm^3/a)	Total Use (Mm^3/a)	Domestic Us (Mm^3/a)e	Population	Groundwater Dependent Population	l/c/d
	Livestock (Mm^3/a)	Livestock (m^3/a/ha)	Municipal	Irrigation	Mining	Industry	Schedule1 (Mm^3/a)						
D52F	0.000	0.00	0.000	0.000	0.000	0.000	0.008		0.009	0.009	134	123	200
D53A	0.070	0.36	0.000	0.000	0.000	0.000	0.014		0.089	0.020	787	269	200
D53B	0.065	0.38	0.000	0.000	0.000	0.000	0.013		0.106	0.041	1014	565	200
D53C	0.071	0.38	0.300	0.008	0.000	0.000	0.015	0.248	0.342	0.263	5870	4549	158
D53D	0.069	0.38	0.000	0.000	0.000	0.000	0.012		0.102	0.033	1586	453	200
D53E	0.031	0.38	0.000	0.000	0.000	0.000	0.005		0.046	0.015	735	208	200
D53F	0.004	0.00	0.000	0.068	0.500	0.577	0.039		1.193	0.045	1208	622	200
D53G	0.179	0.38	0.000	0.000	0.065	0.000	0.030		0.320	0.077	3622	1048	200
D53H	0.060	0.38	0.000	0.000	0.000	0.000	0.010		0.089	0.029	1403	398	200
D53J	0.017	0.37	0.000	0.000	0.000	0.000	0.006		0.023	0.006	1400	87	200
D54A	0.099	0.65	0.000	0.000	0.000	0.000	0.011		0.111	0.011	181	157	200
D54B	0.264	0.65	0.385	0.702	0.000	0.327	0.052	0.585	1.930	0.637	8789	8600	203
D54C	0.088	0.65	0.000	0.000	0.000	0.000	0.010		0.098	0.010	160	139	200
D54D	0.277	0.55	0.012	0.096	0.000	0.000	0.038		0.423	0.050	850	622	222
D54E	0.104	0.31	0.000	0.011	0.000	0.119	0.023		0.257	0.024	361	327	200
D54F	0.202	0.53	0.000	0.000	0.180	0.000	0.028		0.411	0.029	446	398	200
D54G	0.111	0.25	0.000	0.000	0.000	0.000	0.037		0.152	0.040	1140	553	200
D55A	0.020	0.11	0.000	0.046	0.000	0.000	0.039		0.106	0.039	572	539	200
D55B	0.069	0.55	0.000	0.203	0.000	0.000	0.009		0.281	0.009	135	124	200
D55C	0.027	0.35	0.000	0.167	0.000	0.000	0.012		0.207	0.014	210	193	200
D55D	0.115	0.61	0.056	0.677	0.000	0.000	0.024	0.445	1.262	0.469	1351	1301	988
D55E	0.123	0.55	0.000	0.021	0.000	0.000	0.022	0.192	0.358	0.214	3254	3214	183
D55F	0.158	0.60	0.000	0.087	0.000	0.000	0.025		0.271	0.026	404	353	200
D55G	0.079	0.61	0.000	0.000	0.000	0.000	0.012		0.091	0.013	195	172	200
D55H	0.047	0.41	0.000	0.068	0.000	0.000	0.008		0.123	0.008	121	111	200
D55J	0.005	0.02	0.000	0.027	0.000	0.000	0.014		0.046	0.014	208	192	200
D55K	0.031	0.25	0.000	0.055	0.000	0.000	0.009		0.095	0.009	131	121	200
D55L	0.035	0.28	0.138	0.684	0.000	0.000	0.016	0.221	0.956	0.237	3489	3448	188
D55M	0.049	0.27	0.000	0.018	0.000	0.000	0.012		0.080	0.013	190	175	200

Scheme	GRA II		WARMS 2016 (Mm³/a)				Census 2011	All Towns and ISP (Mm³/a)	Total Use (Mm³/a)	Domestic Us (Mm³/a)e	Population	Groundwater Dependent Population	l/c/d
	Livestock (Mm³/a)	Livestock (m³/a/ha)	Municipal	Irrigation	Mining	Industry	Schedule1 (Mm³/a)						
D56A	0.018	0.35	0.000	0.024	0.000	0.000	0.004		0.045	0.004	54	49	200
D56B	0.018	0.35	0.000	0.130	0.000	0.000	0.004		0.151	0.004	56	51	200
D56C	0.032	0.35	0.000	0.008	0.000	0.000	0.006		0.047	0.007	97	90	200
D56D	0.020	0.32	0.000	0.050	0.000	0.000	0.004		0.074	0.004	64	59	200
D56E	0.036	0.55	0.000	0.000	0.000	0.000	0.005		0.041	0.005	70	65	200
D56F	0.057	0.55	0.000	0.218	0.000	0.000	0.007		0.282	0.007	107	99	200
D56G	0.036	0.55	0.000	0.014	0.000	0.000	0.004		0.054	0.005	67	62	200
D56H	0.010	0.23	0.000	0.005	0.000	0.000	0.003		0.018	0.003	47	43	200
D56J	0.030	0.32	0.000	0.050	0.000	0.000	0.006		0.086	0.007	97	90	200
D57A	0.009	0.10	0.000	0.207	0.000	0.000	0.006		0.222	0.006	95	88	200
D57B	0.099	0.43	0.000	0.054	0.000	0.000	0.016		0.169	0.016	238	220	200
D57C	0.001	0.01	0.144	0.000	0.000	0.000	0.007	0.137	0.145	0.144	1462	1432	276
D57D	0.104	0.23	0.000	0.119	0.000	0.000	0.044		0.364	0.141	2100	1932	200
D57E	0.074	0.38	0.000	0.000	0.000	0.000	0.015		0.105	0.032	1350	435	200
D58A	0.000	0.01	0.000	0.036	0.000	0.000	0.006		0.042	0.006	88	81	200
D58B	0.001	0.01	0.000	0.000	0.000	0.000	0.010		0.025	0.024	345	327	200
D58C	0.001	0.00	0.000	0.079	0.000	0.000	0.018		0.099	0.020	292	269	200
D61A	0.080	0.55	0.800	1.519	0.000	0.000	0.032	0.564	2.195	0.596	5398	4810	340
D61B	0.069	0.58	0.000	0.487	0.000	0.000	0.015		0.573	0.017	271	232	200
D61C	0.078	0.66	0.000	0.306	0.000	0.000	0.013		0.397	0.014	215	186	200
D61D	0.045	0.69	0.000	0.461	0.000	0.000	0.007		0.514	0.008	119	103	200
D61E	0.079	0.73	0.312	0.613	0.000	0.000	0.028	0.722	1.443	0.750	8801	8481	242
D61F	0.064	0.73	0.000	0.163	0.000	0.000	0.010		0.237	0.010	160	138	200
D61G	0.054	0.73	0.000	0.239	0.000	0.000	0.009		0.302	0.009	138	119	200
D61H	0.079	0.73	0.000	0.084	0.000	0.000	0.012		0.176	0.013	201	174	200
D61J	0.102	0.66	0.000	0.184	0.000	0.000	0.015		0.302	0.016	246	213	200
D61K	0.109	0.68	0.000	0.050	0.000	0.000	0.016		0.175	0.016	250	219	200
D61L	0.066	0.65	0.000	0.020	0.000	0.000	0.012		0.098	0.013	191	172	200
D61M	0.064	0.68	0.000	0.124	0.000	0.000	0.011		0.199	0.011	175	157	200

Scheme	GRA II		WARMS 2016 (Mm³/a)				Census 2011	All Towns and ISP (Mm³/a)	Total Use (Mm³/a)	Domestic Us (Mm³/a)e	Population	Groundwater Dependent Population	l/c/d
	Livestock (Mm³/a)	Livestock (m³/a/ha)	Municipal	Irrigation	Mining	Industry	Schedule1 (Mm³/a)						
D62A	0.147	0.65	0.350	0.134	0.000	0.000	0.060	0.349	0.690	0.409	5667	5526	203
D62B	0.202	0.65	0.054	0.065	0.000	0.000	0.040	0.146	0.453	0.186	1704	1605	318
D62C	0.174	0.82	0.000	0.211	0.000	0.000	0.037		0.488	0.103	1473	1415	200
D62D	0.136	0.57	2.567	1.269	0.000	0.025	0.070	2.798	4.299	2.868	29400	29097	270
D62E	0.173	0.90	0.000	0.359	0.000	0.000	0.024		0.556	0.024	365	331	200
D62F	0.201	1.19	0.000	0.257	0.000	0.000	0.022		0.482	0.023	361	312	200
D62G	0.174	0.68	0.098	0.096	0.000	0.050	0.156	0.146	0.622	0.302	3473	3307	250
D62H	0.108	0.52	0.000	0.155	0.000	0.000	0.017		0.281	0.018	346	243	200
D62J	0.142	0.65	0.000	0.122	0.000	0.018	0.021		0.304	0.022	427	301	200
D71A	0.093	0.77	0.000	0.042	0.085	0.000	0.018		0.240	0.019	430	263	200
D71B	0.169	0.59	0.190	1.561	0.164	0.000	0.061	0.500	2.455	0.561	7518	6964	221
D71C	0.103	0.65	0.000	0.006	0.014	0.000	0.020		0.143	0.021	446	288	200
D71D	0.098	0.57	0.043	0.394	0.000	0.000	0.028	0.148	0.668	0.176	2032	1773	272
D72A	0.022	0.16	0.000	0.259	0.000	0.000	0.017		0.298	0.017	2275	234	201
D72B	0.038	0.15	0.000	0.164	0.004	0.000	0.043		0.248	0.043	13042	584	200
D72C	0.032	0.12	0.168	0.181	0.000	0.000	0.042	0.245	0.499	0.287	3340	2976	264
D73B	0.199	0.54	0.000	0.272	0.117	0.000	0.060		0.652	0.064	1519	878	200
D73C	0.222	0.36	0.000	0.000	0.000	0.000	0.085		0.430	0.208	3442	2847	200
D73D	0.046	0.11	0.000	0.000	0.000	0.000	0.053		0.099	0.053	13170	720	200
D73E	0.062	0.16	0.018	0.063	0.000	0.015	0.040		0.198	0.058	24408	551	289
D73F	0.077	0.17	0.000	0.000	0.000	0.000	0.091		0.168	0.091	96191	1251	200
D81A	0.082	0.35	0.000	0.000	0.000	0.000	0.041		0.122	0.041	9639	557	200
D81B	0.032	0.38	0.000	0.000	0.000	0.000	0.004		0.051	0.019	700	258	200
D81C	0.101	0.38	0.000	0.000	0.000	0.000	0.017		0.146	0.046	1789	623	200
D81D	0.068	0.38	0.000	0.000	0.000	0.000	0.012		0.102	0.033	1604	455	200
D81E	0.048	0.38	0.000	0.000	0.000	0.000	0.009		0.057	0.009	1298	116	203
D81F	0.069	0.37	0.000	0.000	0.000	0.000	0.013		0.179	0.110	2470	1508	200
D81G	0.071	0.35	0.000	0.000	0.000	0.000	0.010		0.081	0.010	5427	136	199
D82A	0.059	0.31	0.000	0.000	0.000	0.000	0.008		0.109	0.050	986	684	200

Scheme	GRA II		WARMS 2016 (Mm^3/a)				Census 2011	All Towns and ISP (Mm^3/a)	Total Use (Mm^3/a)	Domestic Us (Mm^3/a)e	Population	Groundwater Dependent Population	l/c/d
	Livestock (Mm^3/a)	Livestock (m^3/a/ha)	Municipal	Irrigation	Mining	Industry	Schedule1 (Mm^3/a)						
D82B	0.147	0.30	0.000	0.000	0.000	0.000	0.014		0.165	0.018	598	240	200
D82C	0.125	0.31	0.000	0.000	0.004	0.000	0.018		0.146	0.018	2855	243	200
D82D	0.092	0.31	0.000	0.000	0.000	0.000	0.014		0.106	0.014	4575	185	200
D82E	0.029	0.31	0.000	0.000	0.000	0.000	0.003		0.035	0.005	157	74	200
D82F	0.032	0.31	0.000	0.000	0.000	0.000	0.003		0.065	0.033	588	451	200
D82G	0.018	0.31	0.000	0.000	0.000	0.000	0.003		0.022	0.003	698	48	183
D82H	0.026	0.31	0.035	0.000	0.000	0.000	0.001	0.015	0.042	0.016	544	527	86
D82J	0.043	0.31	0.000	0.000	0.000	0.000	0.000		0.043	0.000	9	3	200
D82K	0.028	0.31	0.000	0.000	0.000	0.000	0.007	0.065	0.101	0.072	1072	877	226
D82L	0.023	0.31	0.000	0.000	0.000	0.000	0.006		0.030	0.006	3282	87	200
F10A	0.021	0.45	0.000	0.000	0.000	0.000	0.000		0.021	0.000	8	3	200
F10B	0.049	0.45	0.000	0.000	0.000	0.000	0.000		0.049	0.000	18	6	200
F10C	0.052	0.44	0.000	0.000	0.000	0.000	0.000		0.052	0.001	20	7	200
F20A	0.050	0.45	0.000	0.000	0.000	0.000	0.001		0.052	0.002	63	28	200
F20B	0.023	0.45	0.000	0.000	0.000	0.000	0.001		0.024	0.001	35	15	200
F20C	0.027	0.45	0.000	0.000	0.000	0.000	0.007	0.020	0.055	0.027	373	305	245
F20D	0.020	0.44	0.345	0.000	0.000	0.000	0.001	0.409	0.430	0.410	5551	3050	368
F20E	0.019	0.44	0.000	0.000	0.000	0.000	0.000		0.021	0.001	29	19	200
F30A	0.087	0.45	0.000	0.005	0.000	0.000	0.021	0.056	0.169	0.077	1755	1637	128
F30B	0.065	0.45	0.000	0.016	0.000	0.000	0.005		0.095	0.014	322	188	200
F30C	0.074	0.45	0.000	0.000	0.000	0.000	0.012	0.160	0.245	0.172	2639	2468	191
F30D	0.044	0.45	0.846	0.180	0.000	0.000	0.009	0.886	1.119	0.895	12107	1364	1798
F30E	0.056	0.45	0.000	0.000	0.000	0.000	0.015	0.022	0.093	0.037	21518	949	107
F30F	0.065	0.45	0.000	0.000	0.000	0.000	0.004		0.072	0.006	187	87	200
F30G	0.044	0.45	0.159	0.000	0.757	0.000	0.006	0.262	1.068	0.268	3502	3300	223
F40A	0.043	0.43	0.368	0.000	0.084	0.000	0.004	0.077	0.208	0.081	715	635	349
F40B	0.018	0.45	0.000	0.000	0.000	0.000	0.001		0.020	0.002	59	29	200
F40C	0.027	0.45	0.000	0.000	0.000	0.000	0.007		0.046	0.019	315	259	200
F40D	0.033	0.45	0.000	0.000	0.000	0.000	0.002		0.036	0.003	66	41	200

Scheme	GRA II		WARMS 2016 (Mm³/a)				Census 2011	All Towns and ISP (Mm³/a)	Total Use (Mm³/a)	Domestic Us (Mm³/a)e	Population	Groundwater Dependent Population	l/c/d
	Livestock (Mm³/a)	Livestock (m³/a/ha)	Municipal	Irrigation	Mining	Industry	Schedule1 (Mm³/a)						
F40E	0.047	0.45	0.000	0.000	0.000	0.000	0.008	0.092	0.148	0.100	2062	1925	143
F40F	0.030	0.44	0.000	0.000	0.000	0.000	0.035	0.067	0.132	0.102	534	519	538
F40G	0.016	0.45	0.000	0.000	0.000	0.000	0.002	0.003	0.020	0.005	485	475	27
F40H	0.023	0.44	0.000	0.000	0.000	0.000	0.001		0.024	0.001	26	19	200
F50A	0.029	0.23	0.000	0.000	0.000	0.000	0.014	0.006	0.049	0.020	1852	1313	41
F50B	0.027	0.45	0.000	0.023	0.000	0.000	0.002		0.051	0.002	30	22	200
F50C	0.012	0.28	0.000	0.000	0.003	0.000	0.003		0.026	0.011	231	150	200
F50E	0.022	0.45	0.000	0.000	0.000	0.000	0.005	0.009	0.036	0.015	971	939	42
F50F	0.026	0.45	0.000	0.000	0.000	0.000	0.004	0.348	0.378	0.352	2028	1955	493
F50G	0.034	0.44	0.000	0.000	0.013	0.000	0.002		0.050	0.002	39	29	200
F60A	0.009	0.16	0.000	0.000	0.000	0.000	0.004		0.039	0.030	497	406	200
	9.877		7.572627	17.10745	2.373616	1.267646	2.903	11.015	45.357	14.731	419413	157719	

3.9.2 Livestock water use

No data for livestock water use were available from WARMS; hence, livestock water use was obtained from GRA II (DWAF, 2006a). Livestock water use is significant in the WMA and is 9.87 Mm^3/a, varying from 0.1 -1.19 $m^3/ha/a$ over the WMA, being highest in the southeastern region of the WMA (Figure 3.15).

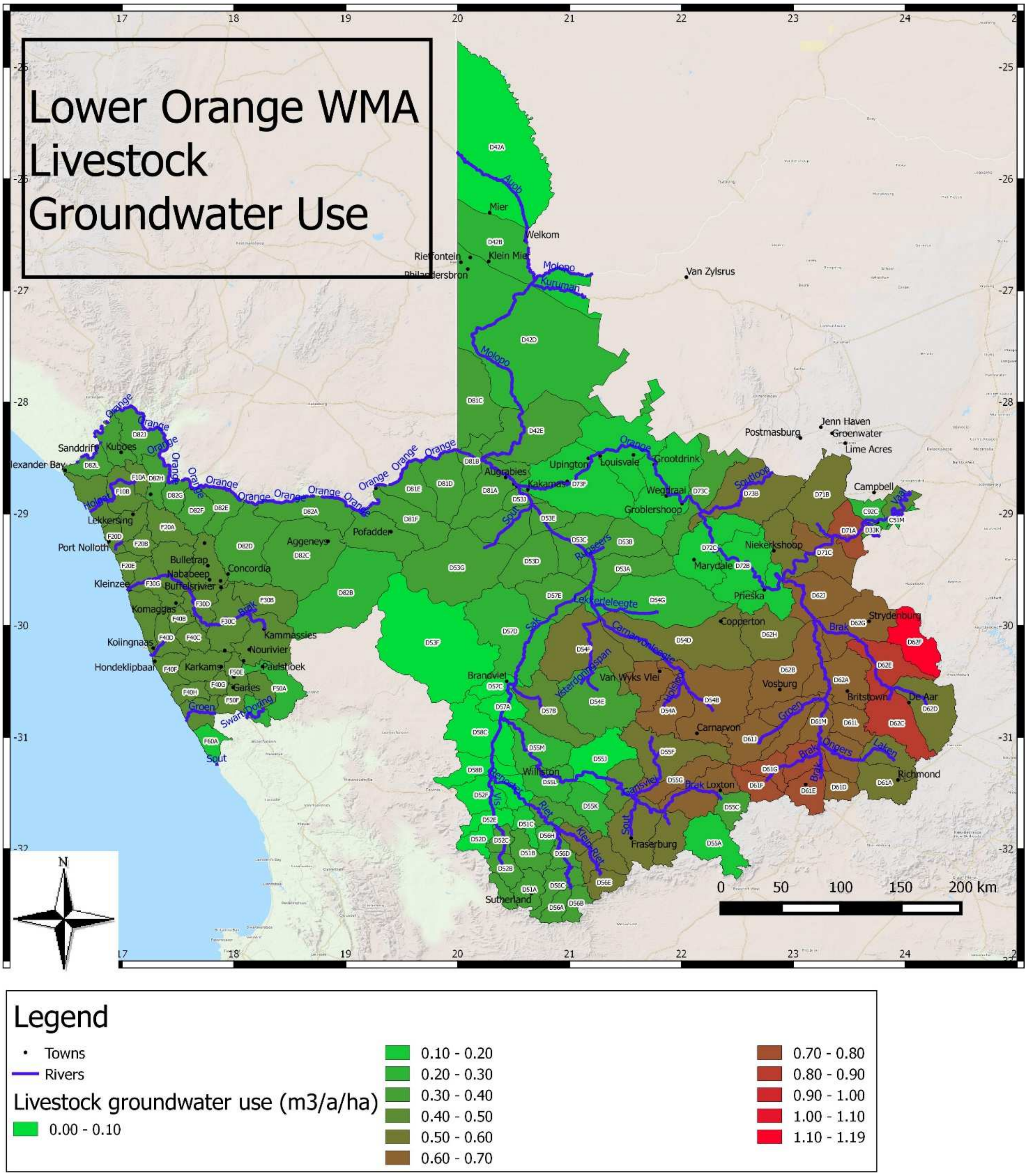


Figure 3.15 Livestock water use in the Lower Orange WMA

3.9.3 Irrigation water use

Irrigation from groundwater is 17.1 Mm^3/a and occurs largely in the Karoo region, with the highest use in the southeast (Figure 3.16).

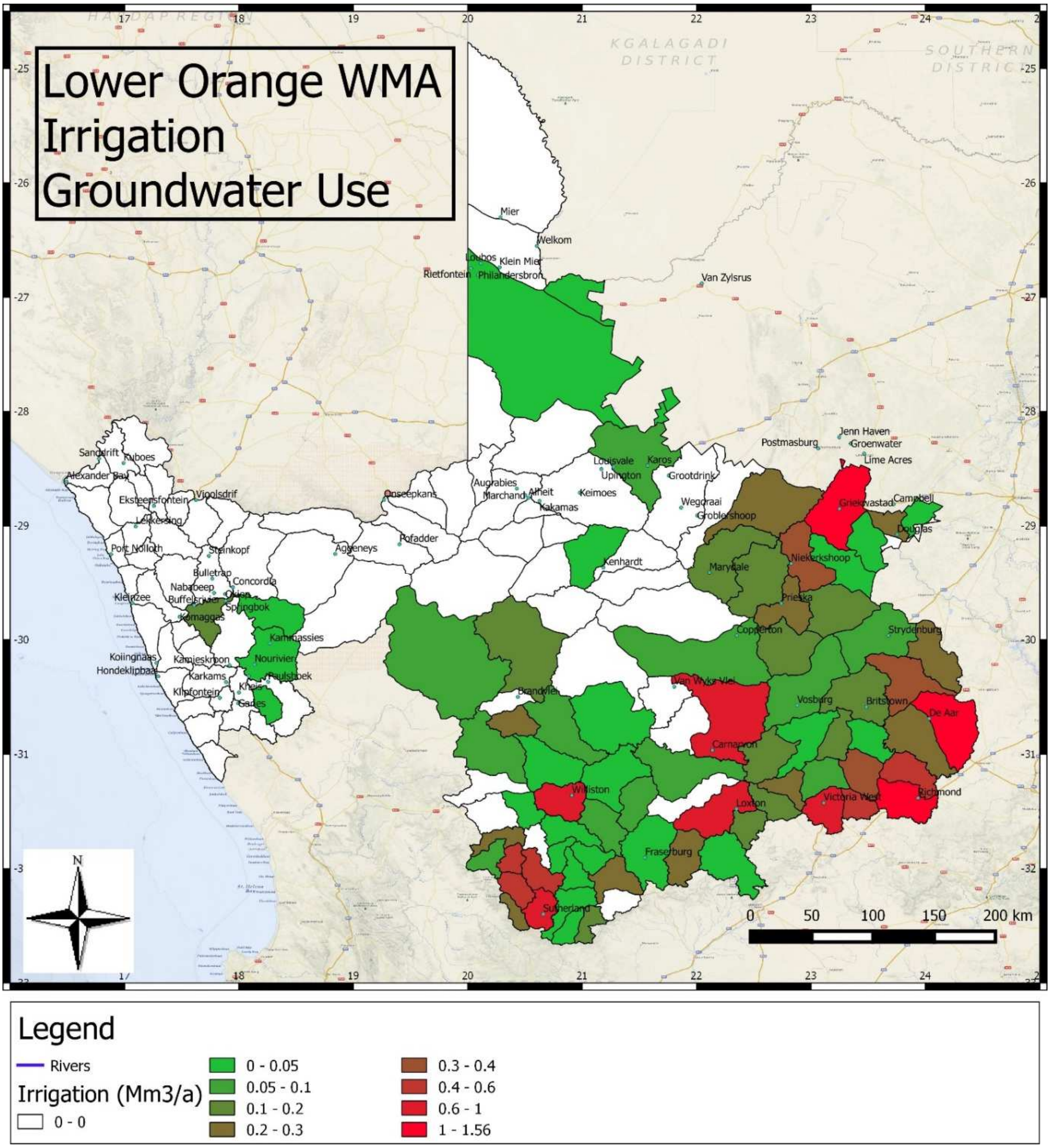


Figure 3.16 Irrigation groundwater use in the Lower Orange WMA

3.9.4 Mining water use

Mining utilises 2.37 Mm^3/a and its distribution is shown in Figure 3.17. The registered mines are listed in Table 3.3.

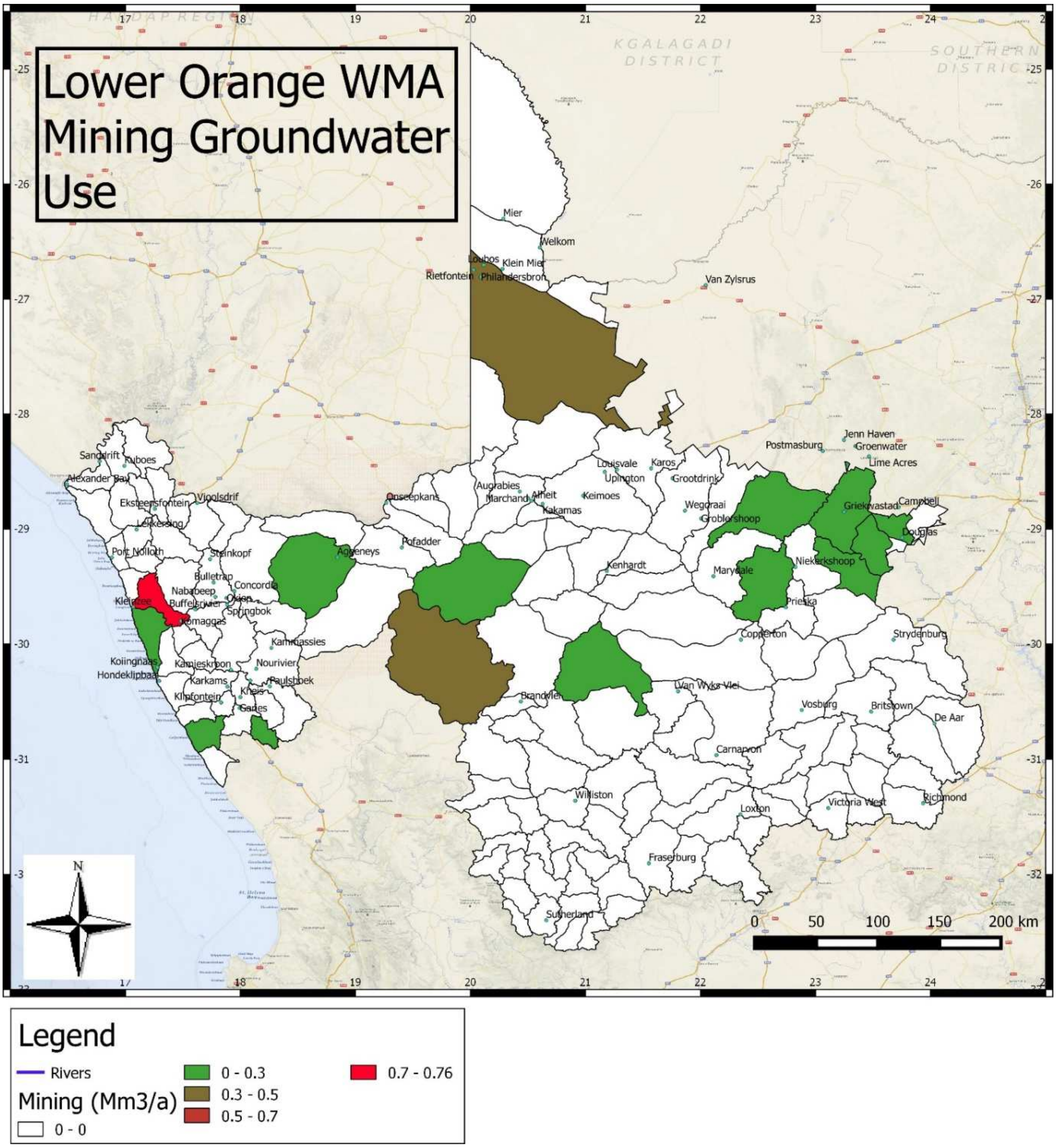


Figure 3.17 Mining groundwater use in the Lower Orange WMA

Table 3-3 Licenced mining water users in the Lower Orange WMA

Mine	Quat	Latitude	Longitude	Licence (Mm^3/a)
Ghaap Boerdery	C92C	-28.8826	23.65917	520
Kalkpoort Soutwerke	D42D	-27.8447	20.88981	21600
Kalkpoort Soutwerke	D42D	-27.8742	20.90788	2000
Upington Super Salt	D42D	-27.6332	20.49265	38538
Saamwerk Soutwerke	D42D	-27.3541	20.82953	129821
Kalkpoort Soutwerke	D42D	-27.7296	20.74158	10800
Kalkpoort Soutwerke	D42D	-27.4453	20.4364	20000
Kalkpoort Soutwerke	D42D	-27.8585	20.9065	2000
Suid Afrikaanse Soutwerke	D42D	-27.3419	20.82576	129821
Saamwerk Soutwerke	D42D	-27.7413	20.74885	2000

Mine	Quat	Latitude	Longitude	Licence (Mm^3/a)
Saamwerk Soutwerke	D42D	-27.6781	20.88902	10800
Kalkpoort Soutwerke	D42D	-27.7481	20.73167	10800
Kalkpoort Soutwerke	D42D	-27.8536	20.89975	2000
Kalkpoort Soutwerke	D42D	-27.8697	20.90876	2000
Saamwerk Soutwerke	D42D	-27.62	20.53	2000
Commisioner's Pan Salt Works	D53F	-30.3021	19.875	250000
Dwaggas Soutwerke	D53F	-30.2091	19.75359	250000
Lafarge Gypsum South Africa	D53G	-29.5326	20.07106	65000
JA Louw	D54F	-30.428	20.75856	90000
WP Louw	D54F	-30.428	20.75856	90000
Stander Familie	D71A	-29.3605	23.53479	5000
CT Bosman	D71A	-29.1325	23.64234	40000
CT Bosman	D71A	-29.1325	23.64234	40000
Dirleton Minerals and Energy	D71B	-28.7745	23.44558	46000
Dirleton Minerals and Energy	D71B	-28.6476	23.2632	46000
Mvelaphanda Exploration	D71B	-29.1094	23.30361	26000
Dirleton Minerals and Energy	D71B	-28.772	23.38886	46000
Stander Familie	D71C	-29.4289	23.51874	5000
Damara Beleggings	D71C	-29.2036	23.1522	3859.7
Stander Familie	D71C	-29.4077	23.51058	5000
JG Saaiman	D72B	-29.5365	22.69343	3993
Lime-Chem Resources	D73B	-28.8753	22.71459	68290.2
Lime-Chem Resources	D73B	-28.8801	22.71948	48214.8
Marlin Granite	D82C	-29.2592	18.94414	3500
Bontekoe Mining	F30G	-29.58	17.32305	583333
De Beers Consolidated Mines (Namaqualand))	F30G	-29.602	17.2363	173375
Marlin Granite	F50C	-30.7636	18.29436	3000
ASAM Resources SA	F50G	-30.6991	17.68596	13350
De Beers Consolidated Mines (Namaqualand)	F40A	-29.691	17.38525	84000

3.9.5 Industrial water use

Licenced Industrial water use is 1.27 Mm^3/a and its distribution is shown in Figure 3.18. Registered users are listed in Table 3.4.

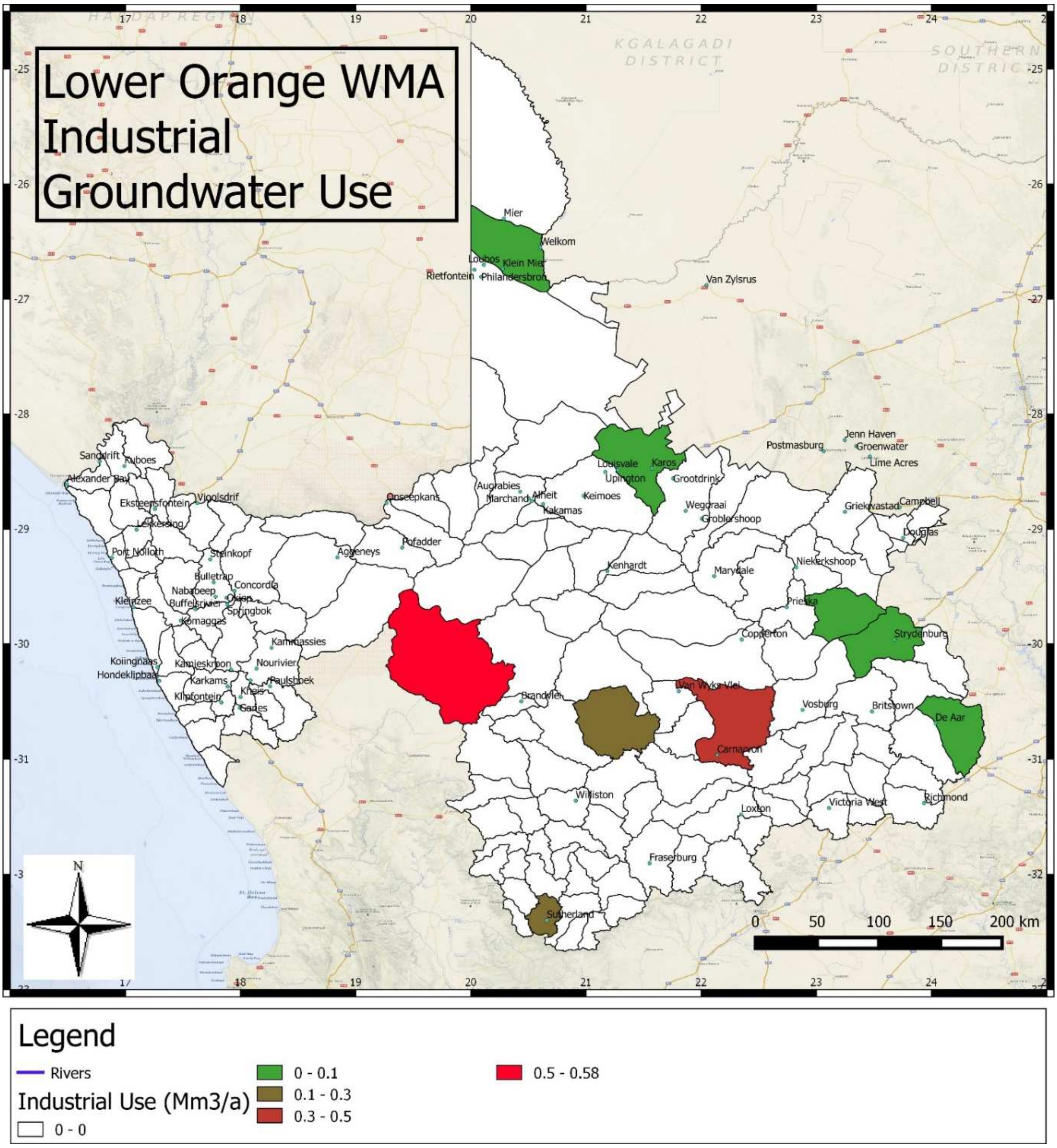


Figure 3.18 Industrial groundwater use in the Lower Orange WMA

Table 3-4 Licenced industrial water users in the Lower Orange WMA

User	Quat	Latitude	Longitude	Licence (Mm^3/a)
South African National Parks	D42B	-26.4816	20.60783	7300
Kareeberg Municipality: Carnarvon	D54B	-30.9306	22.16608	326705
National Research Foundation	D54E	-30.7263	21.45811	1550.52
National Research Foundation	D54E	-30.7524	21.43031	238.68
National Research Foundation	D54E	-30.7179	21.47489	2385.52
National Research Foundation	D54E	-30.7097	21.47094	7156.44
National Research Foundation	D54E	-30.7139	21.4595	238.68
National Research Foundation	D54E	-30.7092	21.39539	238.68

User	Quat	Latitude	Longitude	Licence (Mm^3/a)
Thembelihle Local Municipality: Hopetown	D62G	-29.9093	23.58314	25120
Thembelihle Local Municipality: Hopetown	D62G	-29.9086	23.58022	25120
JC Strauss Eiendomme	D73E	-28.5433	21.20967	15000
Karoo Hoogland Municipality: Sutherland	D51A	-32.38	20.63	130000
Saltcor	D53F	-30.3347	20.17711	300000
JM Strauss	D53F	-30.0205	20.09494	18250
Saltcor	D53F	-30.1822	19.48329	120000
JM Strauss Boerdery Beleggings	D53F	-30.0205	20.09495	18250
Dik Pens Sout	D53F	-30.1822	19.48329	120000
National Research Foundation	D54E	-30.7226	21.41039	956.52
National Research Foundation	D54E	-30.7548	21.43011	238.68
National Research Foundation	D54E	-30.7095	21.39511	238.68
National Research Foundation	D54E	-30.7161	21.39411	238.68
National Research Foundation	D54E	-30.7682	21.40881	714.96
National Research Foundation	D54E	-30.7567	21.43011	238.68
National Research Foundation	D54E	-30.7138	21.39608	1192.68
National Research Foundation	D54E	-30.7143	21.39131	69179.4
National Research Foundation	D54E	-30.7493	21.44061	3578.04
National Research Foundation	D54E	-30.7133	21.39308	23855.04
National Research Foundation	D54E	-30.7101	21.39569	357.84
National Research Foundation	D54E	-30.7144	21.3955	1551.28
National Research Foundation	D54E	-30.7518	21.43039	596.52
National Research Foundation	D54E	-30.7286	21.45569	4055.76
De Aar Stone Crushers	D62D	-30.6464	24.01259	3000
SJ Liebenberg	D62J	-29.6855	23.22124	18000
Solar Capital De Aar	D62D	-30.6177	24.06975	1700
Solar Capital De Aar 3	D62D	-30.5966	24.07749	20400

3.9.6 Groundwater use summary

Total groundwater use is 45.36 Mm^3/a, of which 38% is for irrigation. Industry and mining account for 8% of water use, and domestic water use is 32% (Figure 3.19).

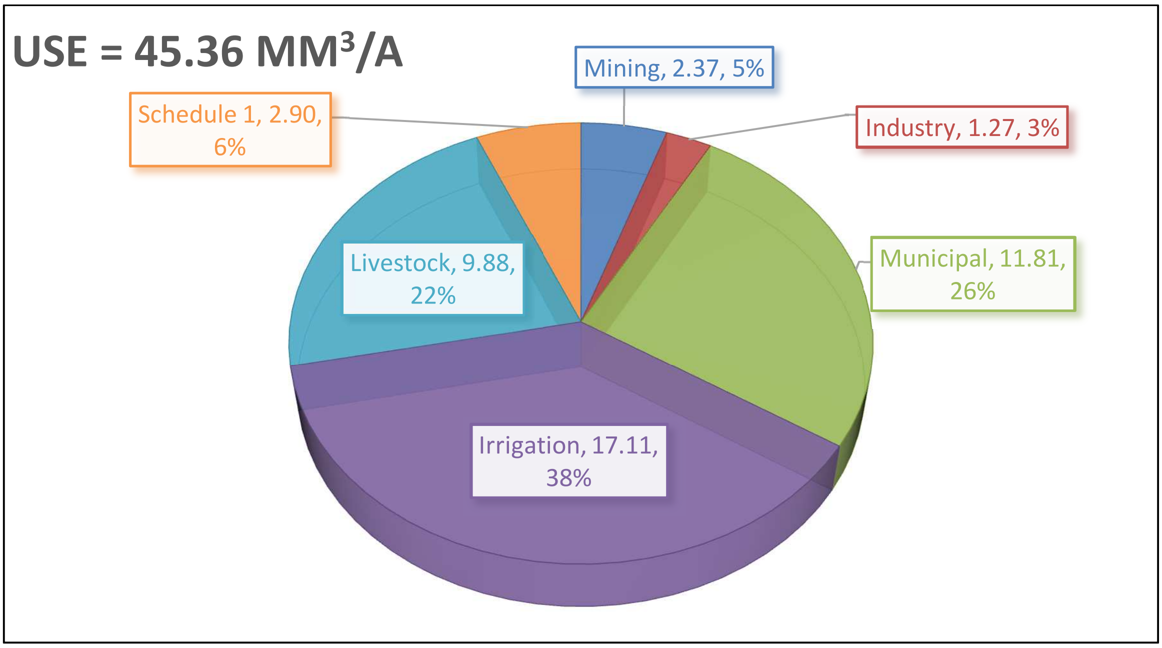


Figure 3.19 Groundwater use summary in the Lower Orange WMA

3.10 GEOLOGY

Very diverse lithostratigraphic units, varying in age from Randian to Quaternary, underlie the Lower Orange WMA. The lithologies cover the broad spectrum of intrusive and extrusive igneous rocks, sedimentary and metamorphic rocks, and unconsolidated sediments.

The geologic units present are described in Table 3.5, and are grouped by potentially similar hydrogeological environments. The selected groupings of geological units are shown in Table 3.5 and Figure 3.20. The grouping was based on:

- Geological age.
- Similar lithology.
- Structural terranes.

The following geological units were identified:

- **Marydale Group:** This greenstone belt is 2910 – 3000 Mega-annum or million annums (Ma) in age and is located from 20 km SSW of Prieska up to the vicinity of Copperton and Marydale. It is at the southwestern edge of the Kaapvaal craton and forms a narrow belt of discontinuous outcrops under Tertiary cover extending for about 100 km in a SE direction. It is sub-divided into the Prieskapoort and Doornfontein Subgroups. They form part of the Namaqualand Metamorphic Province and occur as a compound syncline that is steeply folded and highly metamorphosed to greenstone level.
- **Randian intrusives and volcanics:** This grouping consists of 2700 - 2900 Ma age granites and granitic gneisses outcropping near the Marydale Group.
- **Ventersdorp Supergroup:** The Sodium Group outcrops SE of Prieska and consists of volcanic grits and tuffs, lavas, arkose, porphyry, limestone, chert. It rests on a floor of Randian intrusive granite and is 2640 Ma in age. The Zeekoebaart Formation is exposed south of Boegoeberg dam and consists almost entirely of volcanic andesite and dacite, with some porphyry, tuff and breccia. It has limited exposure related to extensive erosion, and the rocks are only encountered in 2 – 5 very small isolated inliers between Prieska and Douglas. The Allanridge and Bothaville Formations is 2600 Ma and outcrop near Vryburg and west of Kimberley to the NE of the WMA.

- **Transvaal ironstones, sediments and volcanics:** These rocks are found near Vryburg, Prieska and Morokweng. The 2640 Ma Vryburg Formation overlies the Ventersdorp rocks in Griqualand West. The Asbestos Hills banded ironstones and Koegas Subgroup are 2500 - 2400 Ma in age and form the Asbestos Hills and the Kuruman Hills. The Makganyene Formation was deposited over a regional unconformity cut deeply down into the Koegas Subgroup rocks. The Ongeluk Formation is overlain over another unconformity over the Makganyene Formation and is 22200 Ma.
- **Ghaap Group dolomite:** These rocks form the Ghaap plateau and are 2600 - 2500 Ma in age. They are a significant aquifer hence have been separated from the remainder of the Transvaal Group ironstones and other sedimentary rocks. The bulk of the dolomitic outcrop occurs over quaternary catchments D71A, B and C92C and stretches across the WMA boundary into the Lower Vaal WMA. A further narrow strip of dolomite, approximately 50 km long and less than 5km wide outcrops in a roughly north-west to south-east orientation along the Doringberg Fault, west of Peiring. The main body of the outcrop is located in catchment D72B.
- **Olifantshoek Supergroup:** The lower part of this grouping consists of clastic sediments and volcanic rocks, which grade upward to rudaceous sediments. These rocks are encountered west of Postmasburg and east of Olifantshoek and build the foothills of the Langeberg, Korannaberg and Eselberg. They form a prominent north trending mountain range from Boegoeberg northward to the Korannaberg. They overlie Transvaal Supergroup rocks with a regional unconformity and are about 1900 Ma in age.
- **Namaqua-Natal Province:** The region consists of metamorphic rocks formed or metamorphosed between 2000 - 1000 Ma. These rocks range from an assembly of compact sedimentary and volcanic rocks, to extrusive and intrusive rocks including homogenous granites to migmatites and gneisses. The area underlain by the Namaqualand-Natal Province is situated near the Orange River between Prieska to Upington and Springbok. It consists of:
  - Early Mokolian age (2000 Ma) sediments and volcanics that are metamorphosed.
  - Intrusive and extrusive rocks formed during rifting and subduction (1600 - 1200 Ma) and subsequently metamorphosed.
  - Syn and post tectonic granitoids formed between 1200 - 1000 Ma.

  It has been divided into sub-terranes based on marked changes in lithology across structural discontinuities:
  - **Richtersveld subprovince:** The rocks are 2000 Ma and consist of low to medium grade metamorphosed extrusive and intrusive rocks along the Namibian border. Thrusts or shears bound the subprovince. It consists of volcano-sedimentary rocks of the Orange River Group and intrusive granitoid of the Vioolsdrift Suite.
  - **Bushmanland Terrane:** The Terrane consists of granitic gneisses and medium to high-grade deformation of sedimentary and volcanic rocks. The northern boundary of this Terrane is the Richtersveld subprovince and in the east, it abuts against the Kakamas Terrane at the Hartbees River Thrust. It consists of basement gneisses of 2050 - 1700 Ma, mixed sedimentary and volcanic metamorphosed rocks of 1900 - 1200 Ma, and syn and post tectonic Namaqua age intrusive granites and charnokites.
  - **Kakamas Terrane:** The terrane consists of metamorphosed sedimentary rocks and subsequent granitic intrusions. It lies to the east of the Bushmanland Terrane and is bounded in the east by the Boven Rugzeer shear zone. It stretches from the Onseepkans area south 200 km to Kenhardt- Putsonderwater. High-grade metamorphism characterises the rocks of the Terrane.

  - **Areachap Terrane:** This Terrane consists of a NNW trending belt of medium grade 1300 Ma metamorphosed rocks of sedimentary and volcanic origin, and subsequent 1000 Ma granitic intrusions.
  - **Kaaien Terrane:** This Terrane forms the eastern margin of the Namaqua-Natal Province and consists of deformed quartzite and volcano sedimentary rocks. It is bounded in the west by the Brakbosch shear zone and in the east by Dabep Thrust. The Brulpan Group build the Skeurberg to the west of the Langeberg.
  - **Koras Group:** The Koras Group lies in the Kaaien Terrane; however, because it consists of relatively undeformed and unmetamorphosed rocks, it is considered a separate geological unit. It lies unconformably over the metamorphic rocks to the east and north of Upington and post-dates the shear zone, which marks the boundary of the Kaaien Terrane. It is 1180 Ma in age.
- **Namibian Successions:** These rocks are grouped into the Richtersveld Suite, the Gariep Supergroup and the Nama and Vanrhynsdorp Groups, and are intruded by granites. The Richtersveld Suite consists of felsic rocks intruded into rocks of the Vioolsdrift Suite and Orange River Group. The Gariep Supergroup are a meta-volcanic and sedimentary succession that fill a tectonic belt running from Kleinsee to Namibia. They have been extensively deformed and are about 700 Ma in age. The Nama and Vanrhynsdorp Groups were deposited in foreland basins and are separated from The Gariep Belt geographically.
- **The Karoo Supergroup is represented by the Dwyka, Ecca and Beaufort Groups:** They, occupy the southern lobe of the WMA, and comprise thick successions of sedimentary rocks ranging from mudrocks through coarser varieties (sandstones, conglomerates) to diamictites and rhythmites. Karoo or Jurassic dolerite is common throughout the sequence and frequently intrudes older rocks. They have been subdivided based on the following considerations:
  - **Dwyka Tillite:** This massive tillite consists of highly compacted diamictite and is separated from the remainder of the Karoo SuperGroup, as it is a poor aquifer of low permeability and storage.
  - **Carbonaceous Ecca Group shales:** the Prince Albert and Whitehill Formations form thick sequences of black carbonaceous shale with the highest fracking potential where they underlie other Karoo rocks. They have been separated from the remainder of the Ecca Group due to their poor water quality as a unique GRU.
  - **Other Ecca Group shales and sandstones:** Ecca Group rocks are of marine origin and are often more saline than Karoo rocks that are younger in the Sequence. Consequently, they are treated separately.
  - **Beaufort Group rocks**: Are of fluviatile and generally of continental origin. Their salinity is related to low recharge rather than connate marine water like in the Ecca.
- **Sutherland Suite:** This 66 Ma Cretaceous dome structure is an intrusion consisting of volcanic breccia, carbonatite, trachyite and olivine melilitite. Water quality can be poor but it is of geohydrological relevance due to the fracturing it induced in the surrounding Beaufort Group rocks during intrusion. Since this one intrusion only occurs in the Beaufort Group, it is grouped with the Beaufort Group.
- **Quaternary and Tertiary dune deposits**, consisting of “Kalahari red sands”, occupy the extreme northern part of the WMA bordering on Namibia. These dune deposits are of considerable thickness and comprise fine aeolian sands with occasional coarser gravel deposits.

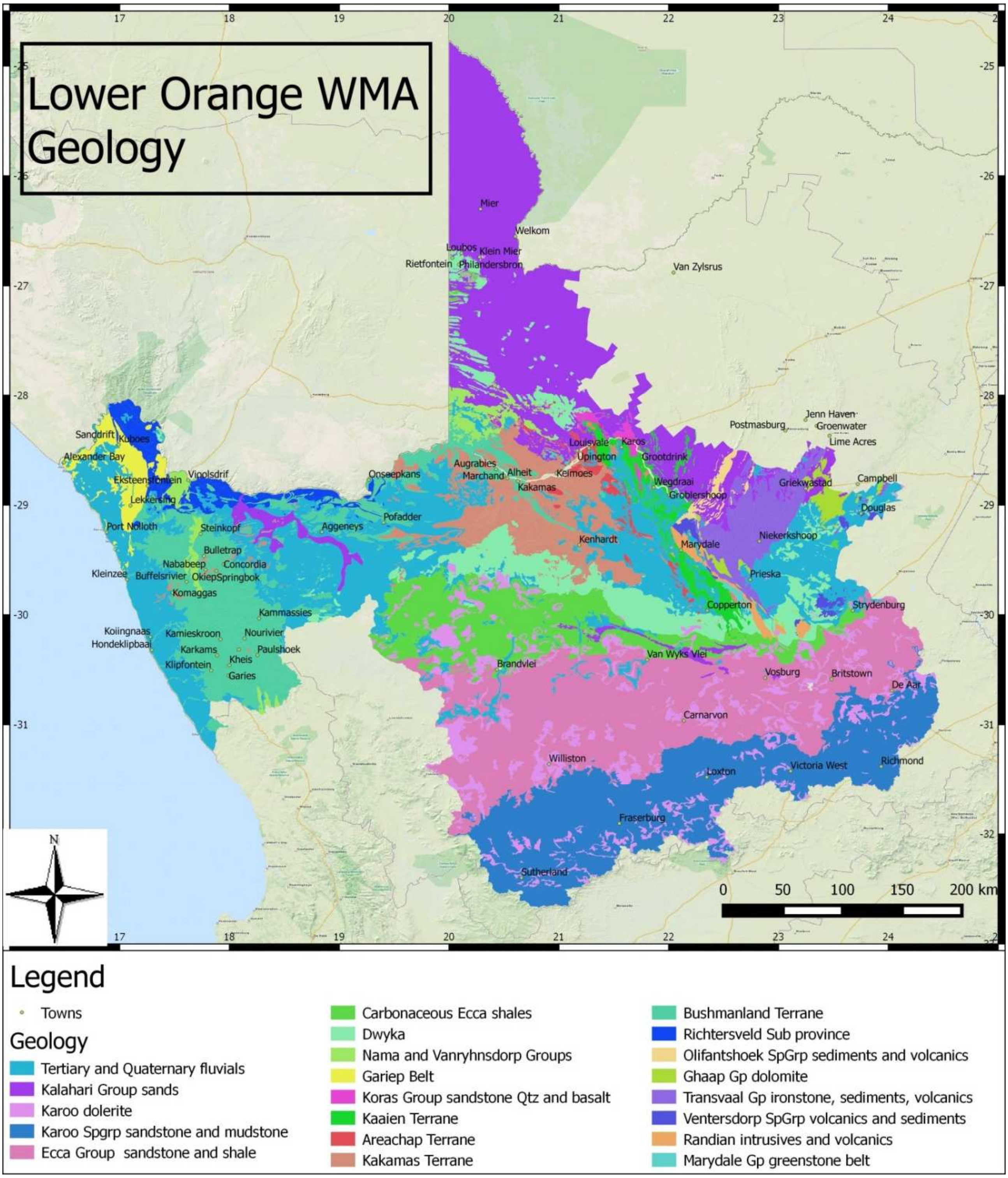


Figure 3.20 Simplified geology of the Lower Orange WMA

Table 3-5 Lithological Units of the lower Orange WMA

Age	SuperGroup	Group	Subgroup	Formation/Suite	Lithology	Simplified Group
Randian		Marydale	Prieskapoort		Conglomerate, subgreywacke, quartzite meta lava and tuff	Marydale Group greenstone belt
			Doornfontein		Banded ironstone, amphibolite, quartzite	
				Skalkseput Granite	Granite	Randian intrusives and volcanics
				Draghoender Gneiss	Granitic gneiss	
	Ventersdorp	Sodium			Grits, tuffs, lavas, arkose, porphyry, limestone, chert	Ventersdorp Supergroup volcanics and sediments
				Zeekoebaart	Andesite, dacite, porphyry, tuff and breccia	
Vaalian				Bothaville	Conglomerate, sandstone, quartzite	
				Allanridge	andesite	
	Transvaal			Vryburg	Siltstone, shale, quartzite, lava	Transvaal Group ironstone, sediments, volcanics
		Ghaap	Schmidtsdrif		Dolomite, shale, limestone, sandstone	Ghaap Group Dolomite
			Campbell Rand		Dolomite, chert, limestone	
			Asbestos Hills		Banded ironstone, amphibolite, shale	Transvaal Group ironstone, sediments, volcanics
			Koegas		Mudstone, amphibolite, quartzite, jaspilite, dolomite, ironstone	
		Postmasburg		Makganyene	Diamictite, jaspilite, dolomite, sandstone, siltstone	
			Cox	Ongeluk	andesite	
		Pretoria		Daspoort	quartzite	
	Olifantshoek			Lucknow	Quartzite, phyllitic shale, lava	Olifantshoek Supergroup sediments and volcanics
				Hartley	Andesitic lava, tuff, conglomerate	
Mokolian		Volop	Matsap		Conglomerate, greywacke, sandstone, quartzite	
			Brulsand		quartzite	
	Namaqualand Metamorphic Province	Orange River	De Hoop		Mafic lava, tuff, andesite, porphyry	Richtersveld Subprovince
				Klipneus and Paradysrivier	Tuff, andesitic lava, conglomerate	
				Rosyntjieberg	Quartzite, schist	
				Windvlakte	Volcanics	

Age	SuperGroup	Group	Subgroup	Formation/Suite	Lithology	Simplified Group
			Haib		Porphyry, pumice, tuff, andesite	
				Vioolsdrif	Mafic and ultramafics, diorite, monzonite	
		Bushmanland	Hom and Guadom		Gneiss, amphibolite, metaquartzite, schists, calc-silicates	Bushmanland Terrane
		Okiep	Een Riet and Aardvark		Schist, gneiss, quartzite	
			Khurisberg		Quartzite, schist	
			Garies		Gneiss	
			Bitterfontein		Gneiss, quartzite, schists	
		Grunau			Kinzingite, gneiss	
				Gladkop	gneiss	
				Little Namaqualand	gneiss	
				Spektakel	Granite, gneiss	
				Biesiesfontein	granite	
				Naab granite	granitoid	
		Geelvloer			Quartzite, calc-silicates	Kakamas Terrane
		Korannaland			Gneiss, quartzite, calc-silicates, amphibolite, schists	
				Toeslaan	Kinzingite	
				Naros granite	granite	
				Stolzendfels enderbite	Charnockite	
				Augrabies granite	Granite-gneiss	
			Vyfbeker Metamorphic Suite		Granite, gneiss	
			Keimoes	Cnydas	Granite, monzonite	
				Friersdale charnockite	charnockite	
				Vaalputs gneiss	gneiss	
				Daberas	granodiorite	
				Eendoorn	granite	
				Hoogoor	gneiss	
				Witwater granite	granite	

Age	SuperGroup	Group	Subgroup	Formation/Suite	Lithology	Simplified Group
				Oranjekom Complex	Noriite epidiorite	
				De Bakken Granite	granite	
				Lat River granite	granite	
				Jannelsepan	Amphibolite, schist, calc-silicates, gneiss	Areachap Terrane
				Upington granitoid	granite	
		Brulpan		Groblershoop	Quartzitic schist, metalava	Kaaien Terrane
				Uitdraai	Quartzite, schist	
		Kaaien		Dagbreek	Quartz schist, quartzite, amphibolite, calc-silicates	
				Sultanaoord	Quartzite, phyllite	
		Wilgenhoutsdrif		Zonderhuis	Quartzite, phyllite, schist, greenstones	
				Leerkrans	Schist, greenstones, phyllite,	
		Koras			Sandstone, grit, conglomerate, quartzite, shale, porphyry, tuff, mudstone, basalt	Koras Group sandstone, quartzite and basalt
Namibian				Richtersveld	granites	Gariep belt
				Grootderm	Basalt, andesite, breccia, tuff, schist	
				Oranjemund	Dolomite, phyllite, schist, quartzite	
	Gariep	Port Nolloth		Stinkfontein	Conglomerate, sandstone, quartzite, arkose, dolomite, phyllite,	
				Hilda	Quartzite, arkose, conglomerate, dolomite, schist	
				Numees	Tillite, sandstone, phyllite, dolomite	
				Holgat	Arkose, shale, quartzite, conglomerate, phyllite, limestone, schist	
				Kuboos granite	granite	
		Nama	Kuibis		Sandstone quartzite	Nama and Vanrhynsdorp Group sedimentary
			Schwarzrand		Limestone, shale	
			Fish River		Sandstone, quartzite, , shale	
		Vanrhynsdorp	Knersvlakte		Siltstone, mudstone, shale, sandstone, limestone	
Paleozoic	Karoo	Dwyka			Tillite, shale, mudstone, sandstone	Dwyka tillite
		Ecca		Prince Albert	shale	Carbonaceous Ecca shales
				Whitehill	Shale	

Age	SuperGroup	Group	Subgroup	Formation/Suite	Lithology	Simplified Group
				Tiersberg	Shale. Siltstone, sandstone	Ecca Group sandstone and shale
				Koedesberg	Sandstone, greywacke	
		Beaufort	Adelaide		Mudstone, sandstone	Beaufort Group sandstone and mudstone
Mesozoic				Karoo dolerite	Dolerite	Dolerite
				Sutherland	Breccia, tuff, trachytoid, carbonatite, basalt	Beaufort Group sandstone and mudstone
Cainozoic		Kalahari			Gravel, claystone, calcareous sandstone. sand	Kalahari Group sands
				Quaternary sands	Sand and calcrete of alluvial origin	Quaternary fluvials

3.11 HYDROGEOLOGY

3.11.1 Groundwater Regions

The Vegter groundwater regions (Vegter, 2001) and simplified geology are shown in Figure 3.21. The underlying geology in each region and the quaternary catchments incorporated are described in Table 3.6.

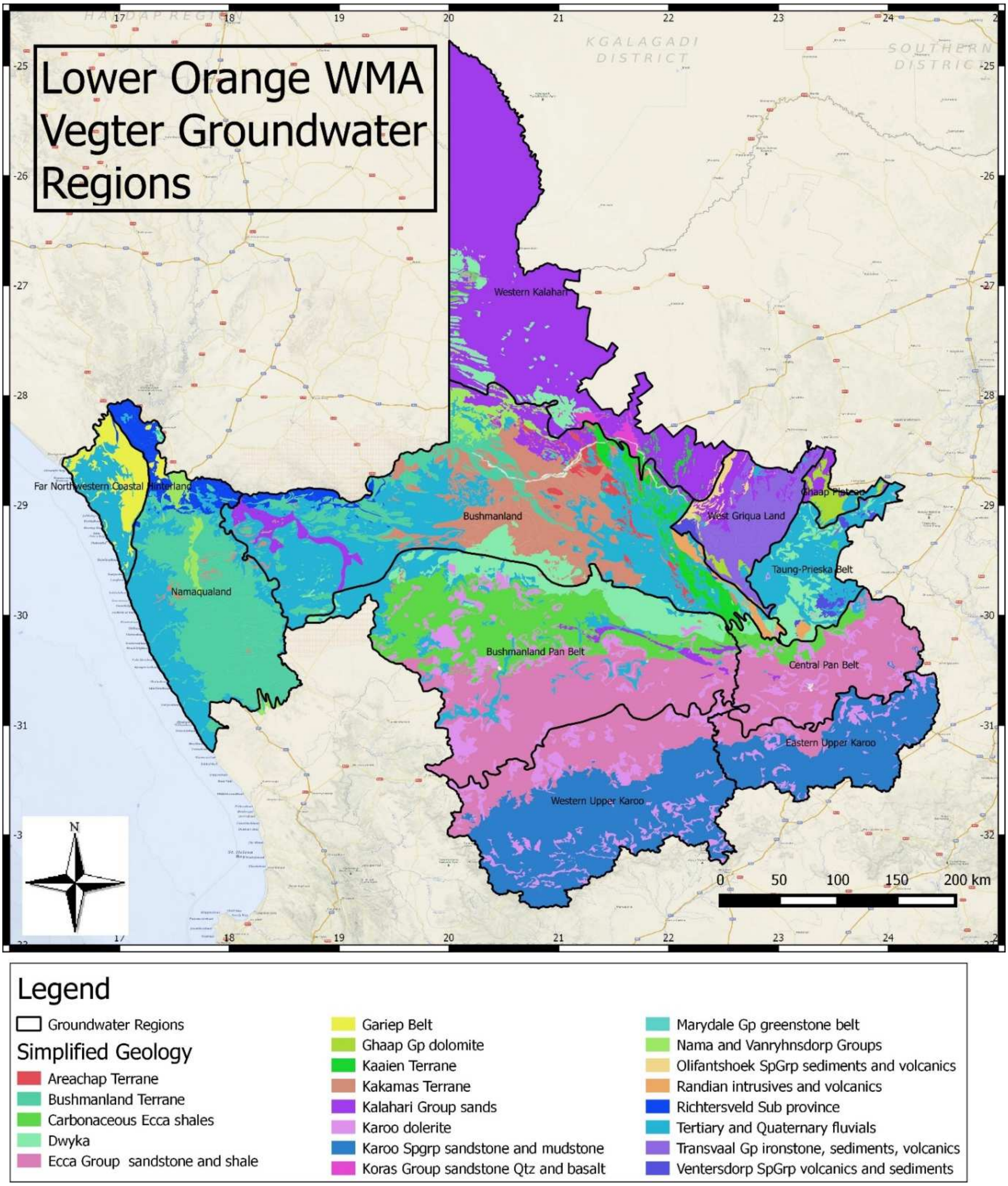


Figure 3.21 Vegter Groundwater Regions of the Lower Orange WMA

Table 3-6 Lithology and catchments of Vegter groundwater Regions

Groundwater Region	Lithology and stratigraphy	Baseflow	Quaternary catchment
23. Western Kalahari	Kalahari Group Gravel, calcareous sandstone and clay over Brulpan Group muscovite, quartzite and schist Wilgenhoutsdrif Group greenstone, quartzite and phyllite Koras Group sandstone quartz porphyry and basalt Dwyka tillite Prince Albert shale Karoo dolerite sills		D42A, D42B, D42C, D42D, D42E D73C, D73D, D73E D81C
24. Ghaap Plateau	Campbell Rand and Schmidtsdrif Subgroups dolomite, limestone, shale and chert		C92C D71A, D71B D72B
	Vryburg Formation shale sandstone and andesite		C92B, C92C D71A, D71B
25. West Griqualand	Transvaal banded ironstone, mudstone, iron formation, riebeckite, shale, diamictite, jaspilllite, andesite and dolomite Olifantshoek quartzite, limestone shale andesite and greywacke Brulpan Group muscovite-quartzite and schist Wilgenhoutsdrif Group phyllite quartzite and lava Koras Group sediments and volcanics		D71B, D71D D72A,D72B, D72C
		x	D73B
26. Bushmanland	Mokolian metasediments and metavolcanics consisting of gneisses, schists, amphibolite, metaquartzite Intrusive granites and gneisses Randian metasediments and volcanics Tertiary and Quaternary fluvial deposits		D42E D53A, D53B, D53C, D53D, D53E, D53G, D53H, D53J D54D, D54G D62H D72A,D72B, D72C D73C, D73D, D73E, D73F D81A, D81B, D81C, D81D, D81E, D81F, D81G D82A, D82B, D82C, D82D
27. Namaqualand	Mokolian metasediments and metavolcanics consisting of gneisses, schists, amphibolite, metaquartzite, andesite, quartz porphyry Intrusive granites, gneisses, granodiorite, tonalite, mafic and ultramafics Tertiary and Quaternary fluvial and coastal deposits		D82D, D82E, D82F, D82G, D82H, D82J F20A, F20B F30A, F30B, F30C, F30D, F30E, F30F, F30G F40A, F40B, F40C, F40D, F40E, F40F, F40G, F40H F50A, F50B, F50C, F50E, F50F, F50G F60A
29. Taung-Preiska belt or Dry Harts-Vaal-Orange lowland	Ventersdorp Supergroup andesite, dacite, quartz porphyry, breccia, conglomerate, shale sandstone Dwyka tillite Prince Albert shale Karoo dolerite		C51M C92B, C92C D33K D62B, D62G, D62H, D62J D71A, D71B, D71C, D71D
31. Central Pan Belt	Ecca Group Tierberg formation shale and dolerite intrusions		D61J, D61K, D61L,D61M D62A, D62B, D62C, D62D, D62E,D62F, D62G, D62H
34. Bushmanland Pan Belt	Dwyka tillite and shale Prince Albert, Whitehill and Tierberg Formations shale and dolerite sheets		D52F D53D, D53G D54A, D54B, D54C, D54D, D54E, D54F, D54G D55M D57A, D57B, D57C, D57D, D57E D58A, D58B, D58C D82B
37. Western Upper Karoo	Waterford Formation shale and sandstone Adelaide subgroup mudstone, shale and sandstone Dolerite intrusions	x	D51A
			D51B, D51C D52A, D52B, D52C, D52D, D52E, D52F D54B

Groundwater Region	Lithology and stratigraphy	Baseflow	Quaternary catchment
			D55A, D55B, D55C, D55D, D55E, D55F, D55G, D55H, D55J, D55K, D55L D56A, D56B, D56C, D56D, D56E, D56F, D56G, D56H, D56J D58A
38. Eastern Upper Karoo	Adelaide and Tarkastad subgroups, mudstone, shale, sandstone and dolerite Waterford Formation shale and sandstone		D61A,D61B,D61C,D61D,D61E,D61F,D61G, D61H, D61J, D61K, D61L D62C, D62D
54. Richtersveld-Far northwestern Coastal Hinterland	Nama Group quartzite, arkose, arenitelimestone, dolomite, diamictite, phyllite, schist, amphibolite, gneiss and ultramafics Cape granite Tertiary raised beach deposits and alluvium		D82K,D82L F10A, F10B,F10C F20B, F20C,F20D,F20E

3.11.2 Aquifer types

Four aquifer types are found in the Lower Orange: namely Intergranular, Intergranular and Fractured (weathered and fractured), Fractured (Structural), and Karst:

- **Intergranular aquifers:** These primary aquifers principally occur in the Kalahari Panhandle and are associated with unconsolidated deposits of Kalahari sand. These can be moderately yield, and yield up to 5 l/s.
- **Intergranular and fractured aquifers:** Secondary fractured and weathered aquifers are found in the sedimentary rocks of Eastern Upper Karoo, and the metamorphics and granitic intrusives of Bushmanland and Namaqualand. Weathering gives rise to low to moderately yielding aquifers where groundwater is stored in the interstices in the weathered saturated zone and in joints and fractures of competent rocks. Borehole yields range from 0.1 - 2.0 l/s, except on the west coast and near the Lower Orange where yields are below 0.1 l/s.
- **Fractured aquifers:** Fractured aquifers in the WMA are common in the Karoo and the Northwestern Coastal Hinterland. The yield of fractured rock aquifers is structurally controlled, as permeability is a function of post-depositional events and associated with faults, fractures, dykes and lithological contacts. Groundwater is found below the weathered zone. The dimension and intensity of fracturing and faulting is highly variable and greatly influences borehole yield.
- **Karstic aquifers:** Karstic aquifers are found on the Ghaap plateau. Karstic aquifers develop in chemically soluble rocks such as dolomite and are characterised by a network of conduits that allow for turbulent flow of groundwater.

The distribution of aquifer types is shown in Figure 3.22.

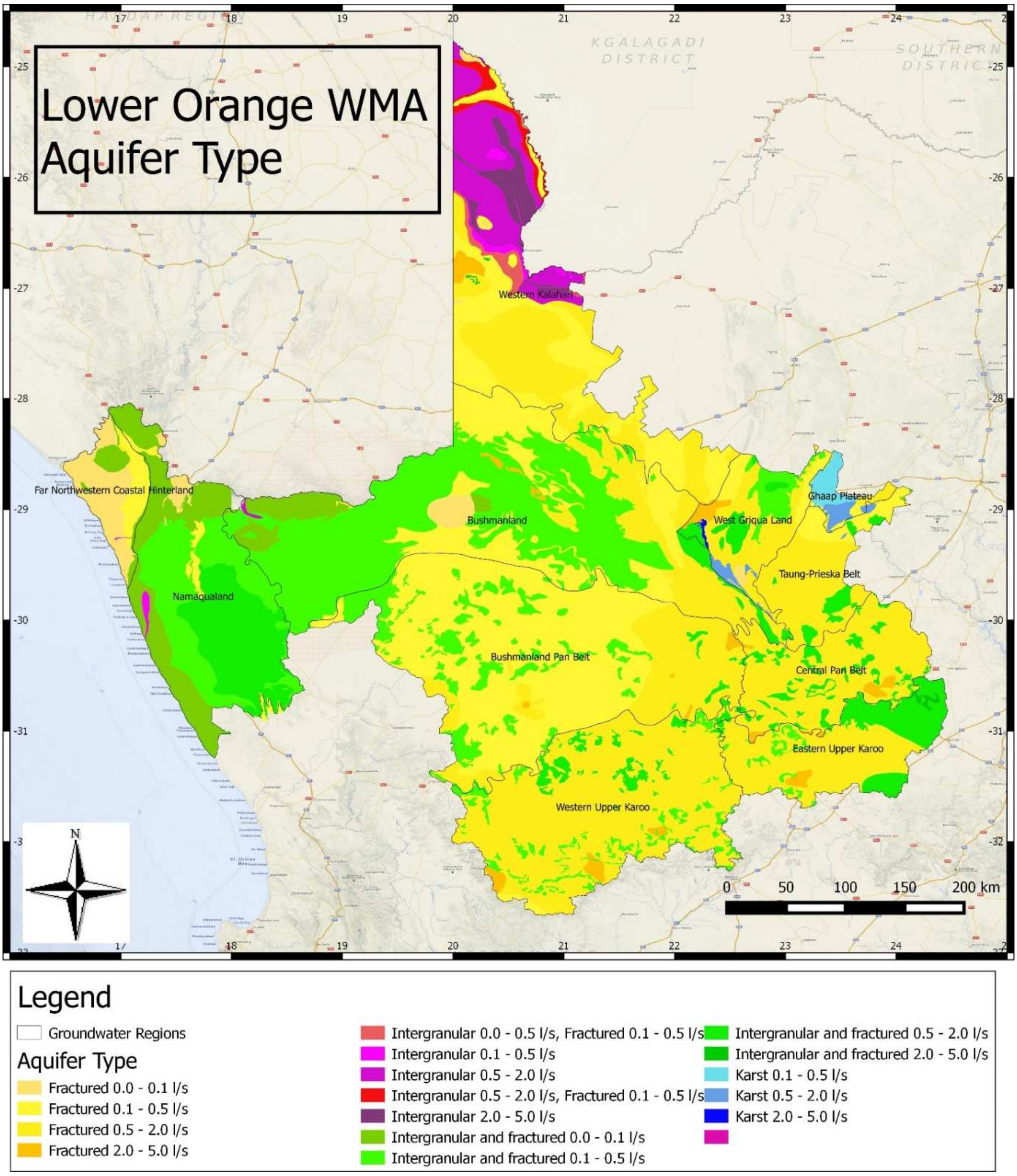


Figure 3.22 Aquifer types and borehole yields in the Lower Orange WMA

3.11.3 Groundwater recharge

The estimation of recharge is one the most important components within the GRDM process since it is used to calculate the available groundwater volume for allocation per unit after taking into account the Reserve requirements. This allocable volume ultimately determines whether additional licence applications for groundwater can be approved. Based on GRA II (DWAF, 2006a), recharge across the WMA varies from close to 0 to 12 mm/a (Figure 3.25).

When recharge is plotted, it was observed that below 150 mm of rainfall, a wide scatter of recharge can be observed and numerous zero values (Figure 3.23). Consequently, recharge was plotted versus rainfall for each groundwater region to derive rainfall recharge relationships (Figure 3.24). These relationships were then used to estimate recharge when recharge in GRA II was given as less than 1 mm. This required correcting recharge for 78 of 178 quaternary units and recharge increased from 396 Mm³/a in GRAII to to 480 Mm³/a for this study by the removal of zero values.

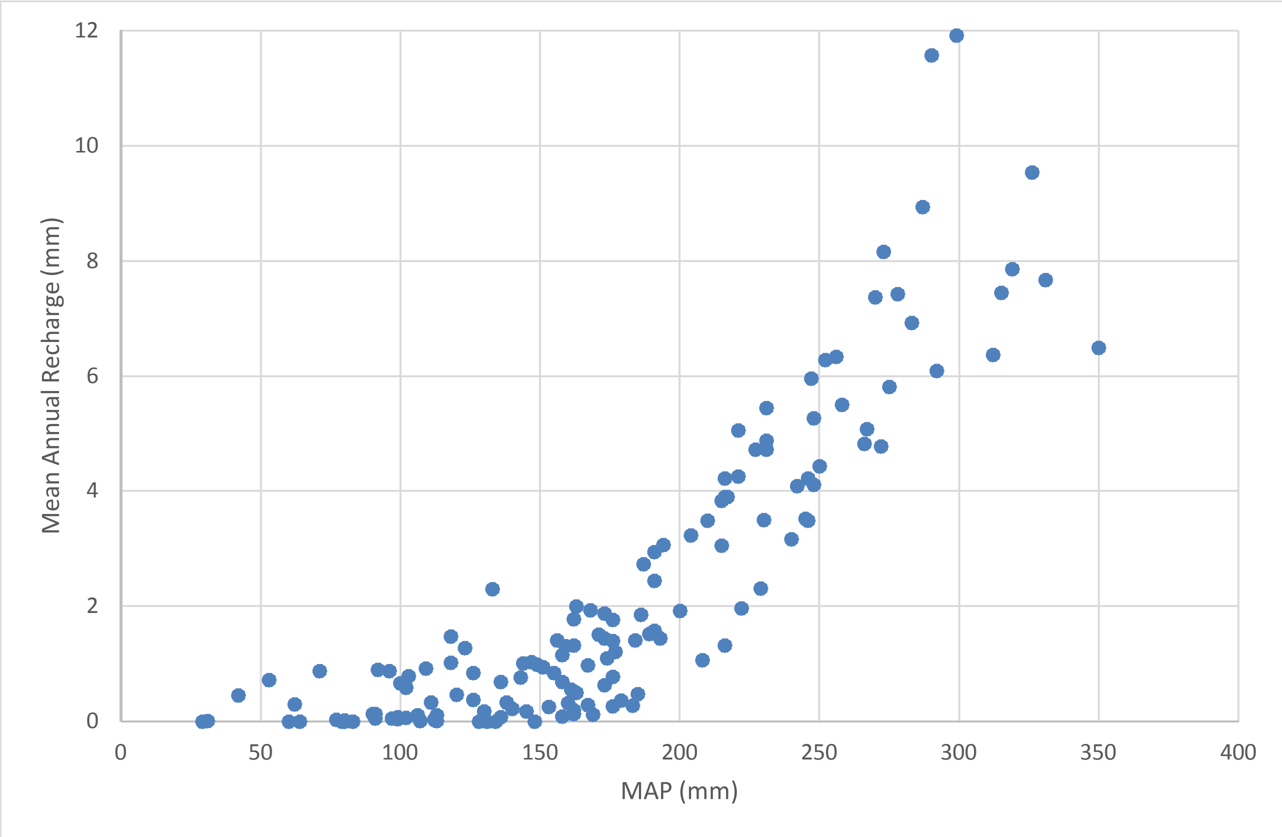
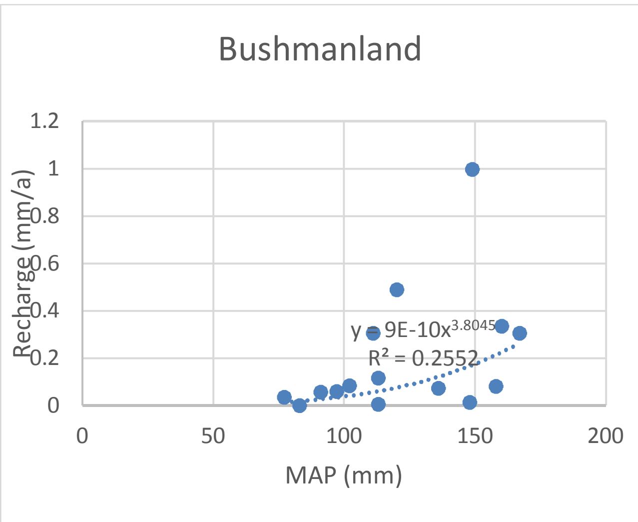
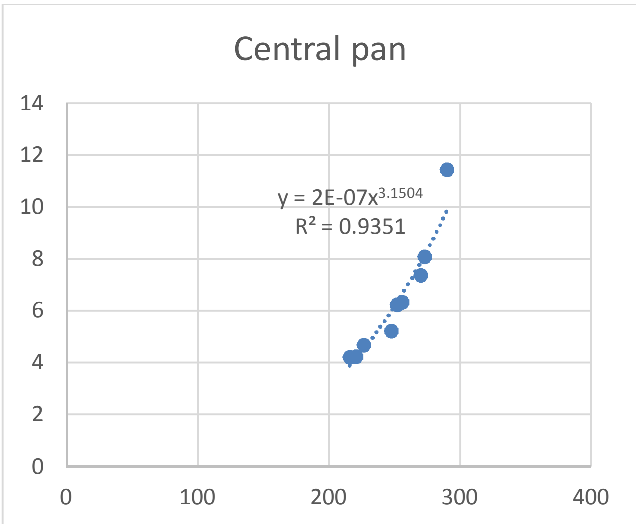


Figure 3.23 Rainfall vs GRAII recharge





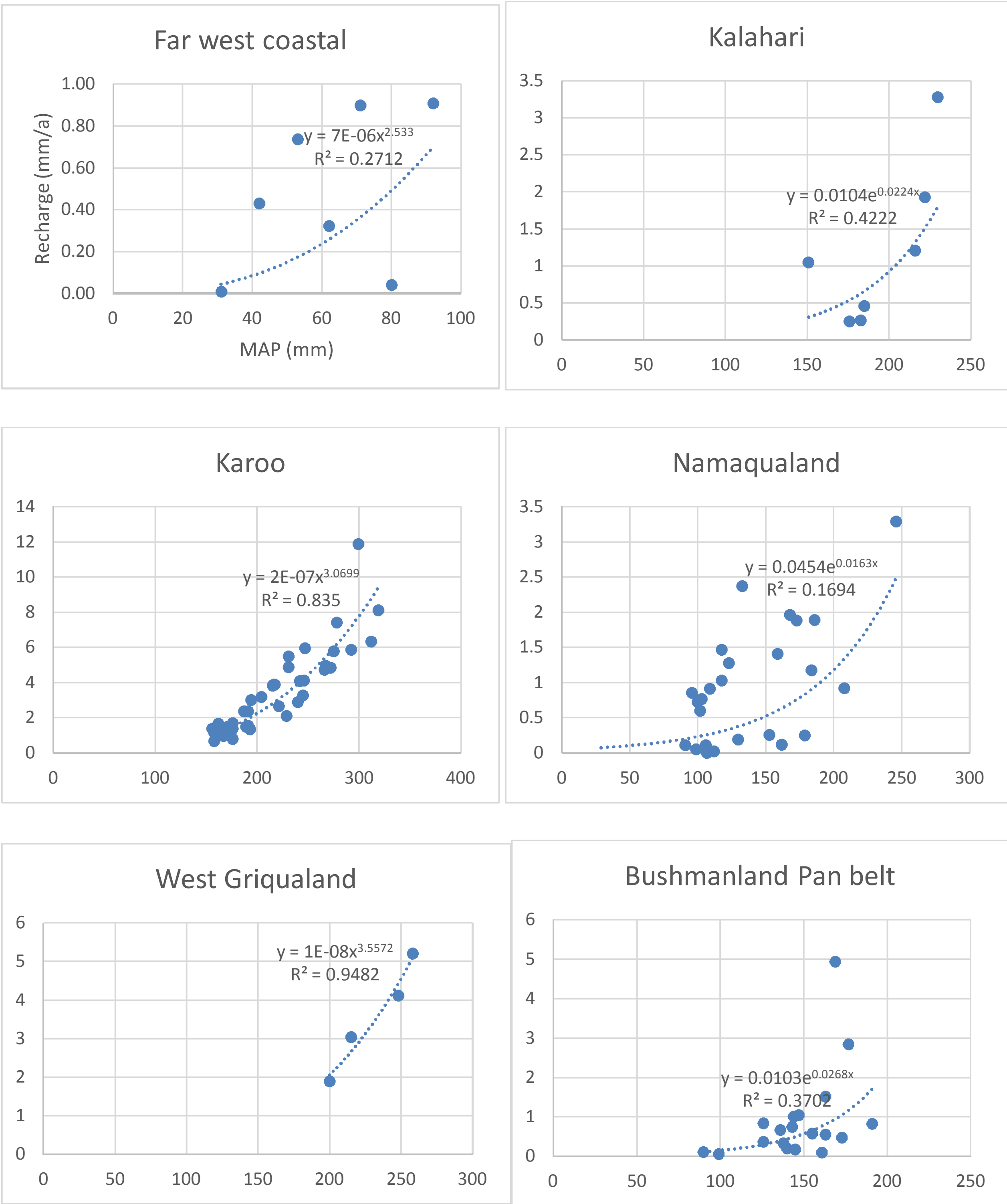


Figure 3.24 Recharge per groundwater region

Recharge is lowest in the central region of the WMA and along the lower Orange River, and highest in the southeast. Total recharge for the WMA is 480.13 Mm^3/a.

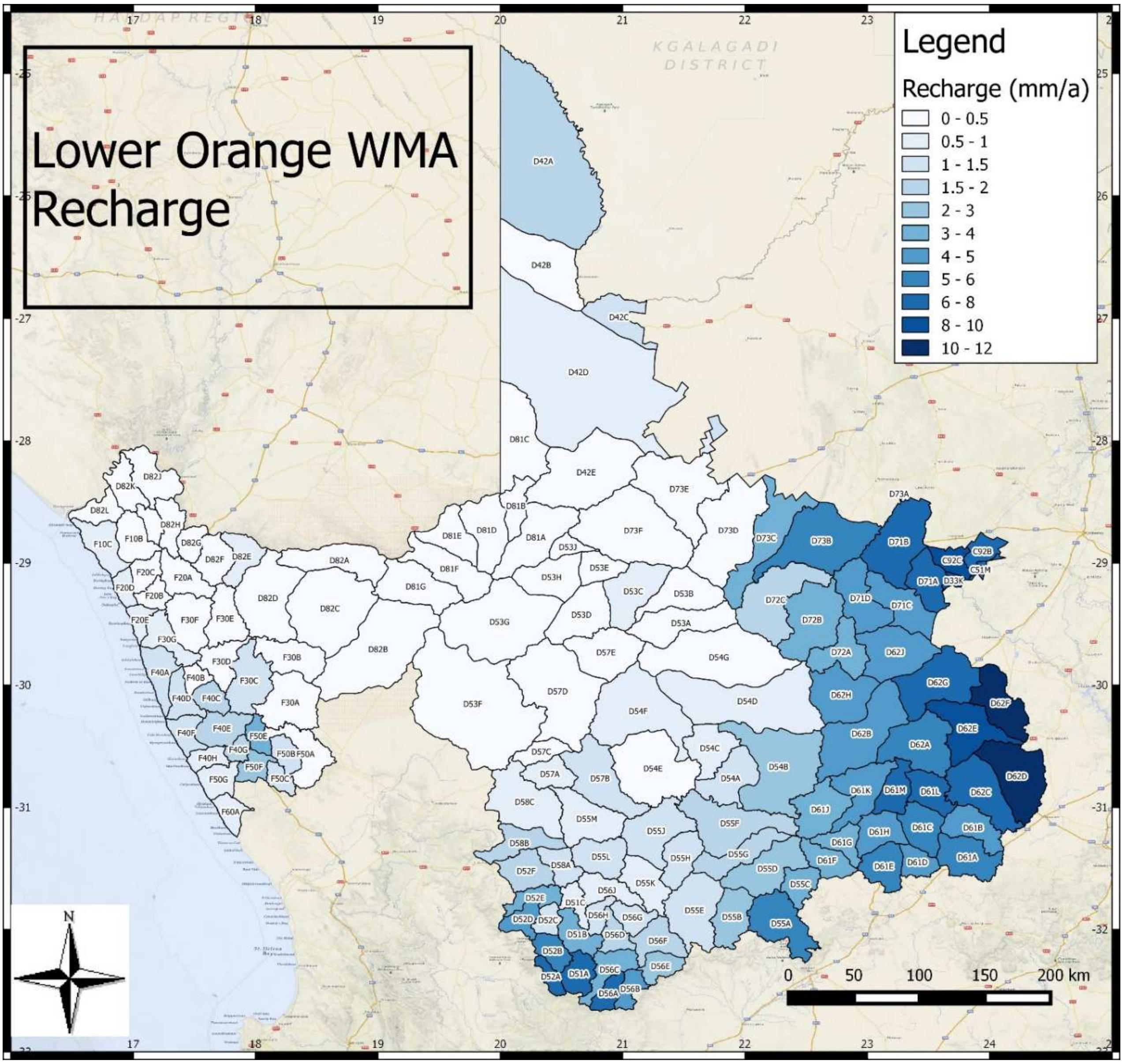


Figure 3.25 Groundwater recharge of the Lower Orange WMA

3.11.4 Borehole yields

Borehole yields as listed in the NGA were grouped per Quaternary catchment to derive the geometric mean borehole yield (Figure 3.26). Mean borehole yields are below 1 l/s in Bushmanland, the Western Kalahari and Namaqualand. In these groundwater regions, more than 80% of boreholes generally yield less than 2 l/s (Figure 3.27). Across the Upper Karoo and the Ghaap Plateau, mean yields exceed 0.8 l/s and reach over 2 l/s and more than 40% of boreholes yield over 2 l/s.

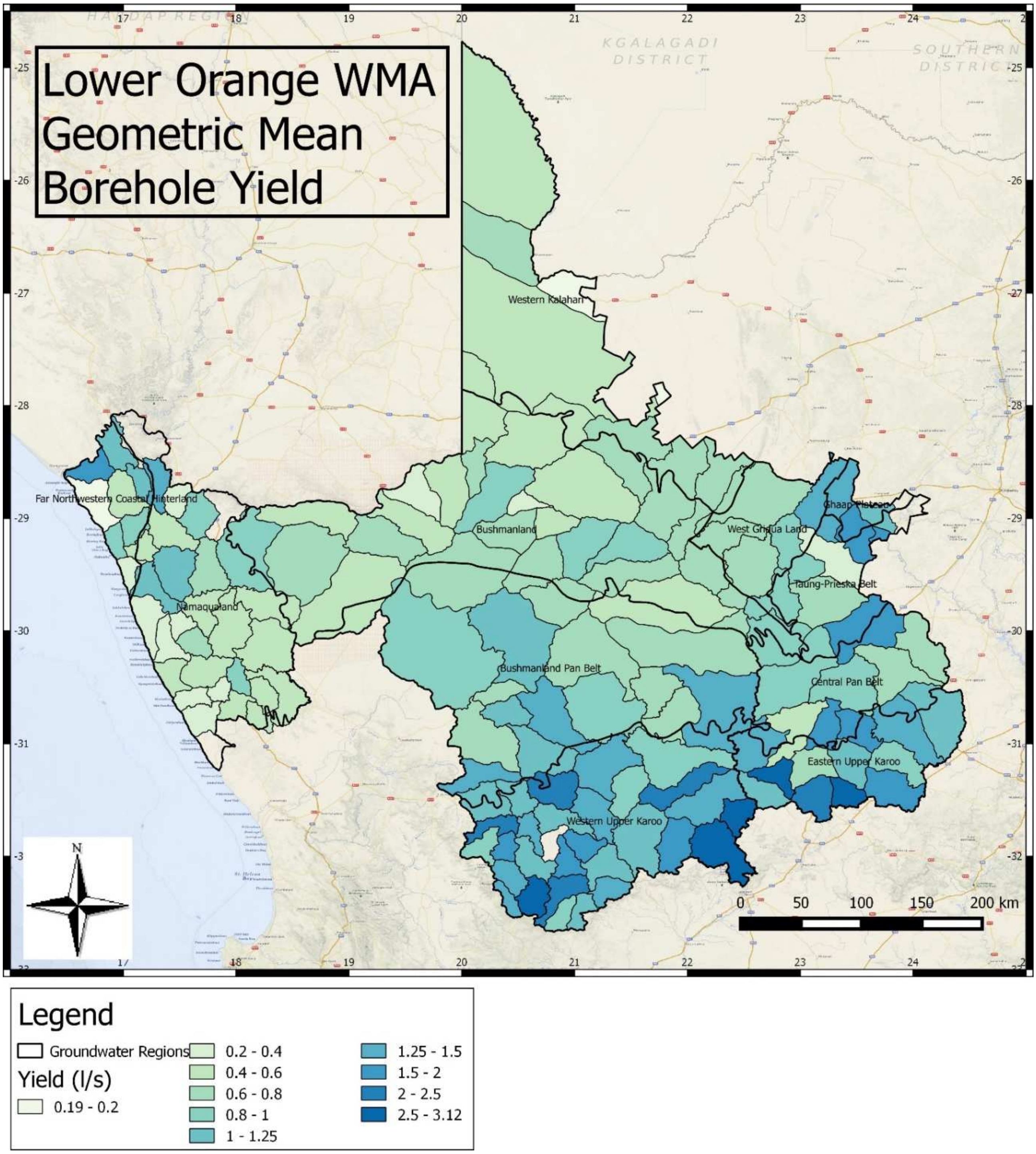


Figure 3.26 Geometric mean borehole yield per Quaternary in the Lower Orange WMA

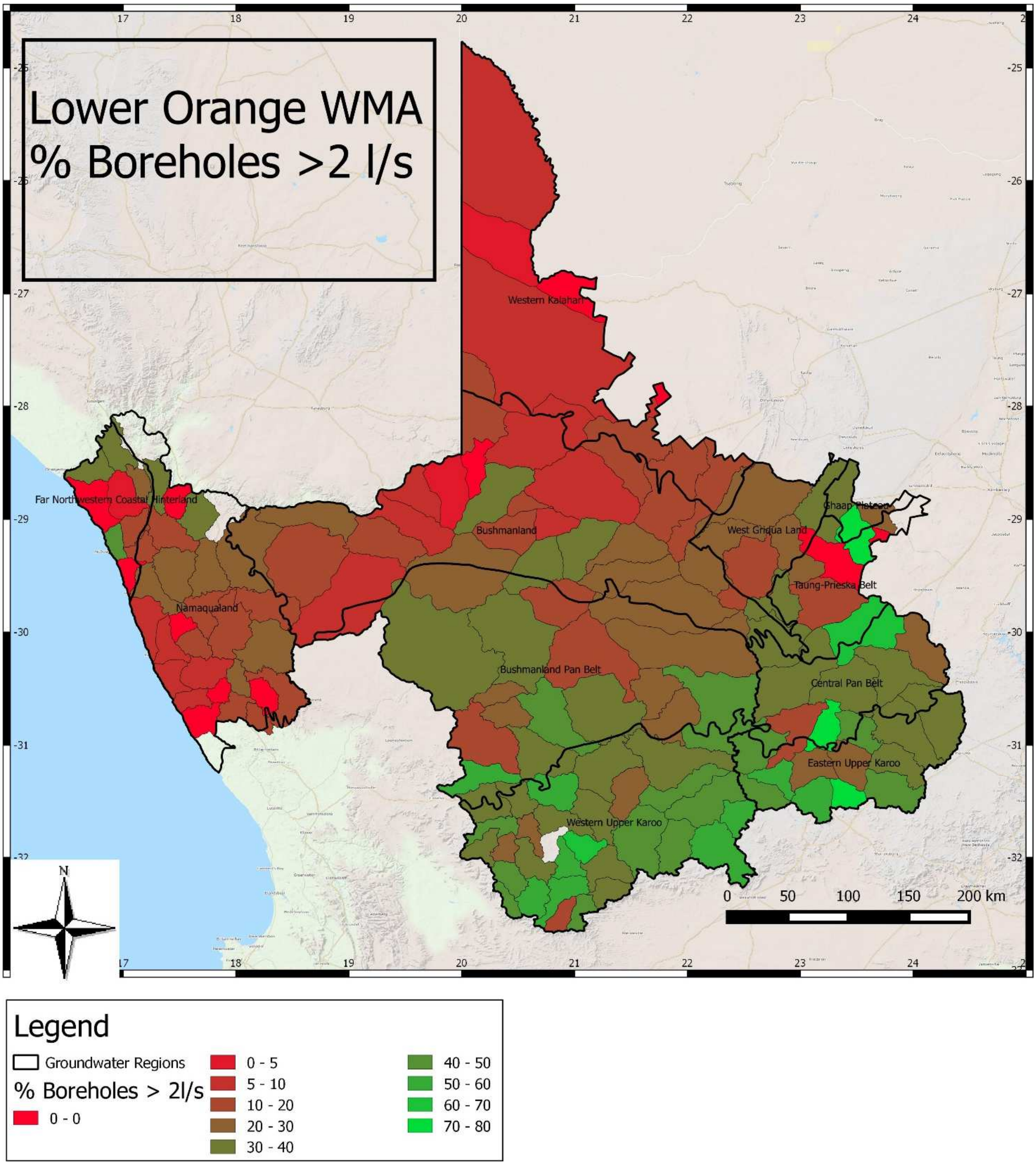


Figure 3.27 Percent of boreholes yielding more than 2 l/s in the Lower Orange WMA

3.11.5 Static water level

The depth to the static water level as listed in the NGA was grouped per Quaternary catchment to derive the mean depth to groundwater (Figure 3.28). The depth to groundwater generally increases northward, being deeper than 40 mbgl in northern and western Bushmanland and the Western Kalahari. Shallow groundwater less than 20 metres below ground level (mbgl) are encountered in central Namaqualand.

In the Upper Karoo, groundwater depth is less than 20 m. The deepest groundwater is in the Western Kalahari, where the mean depth exceeds 60 m.

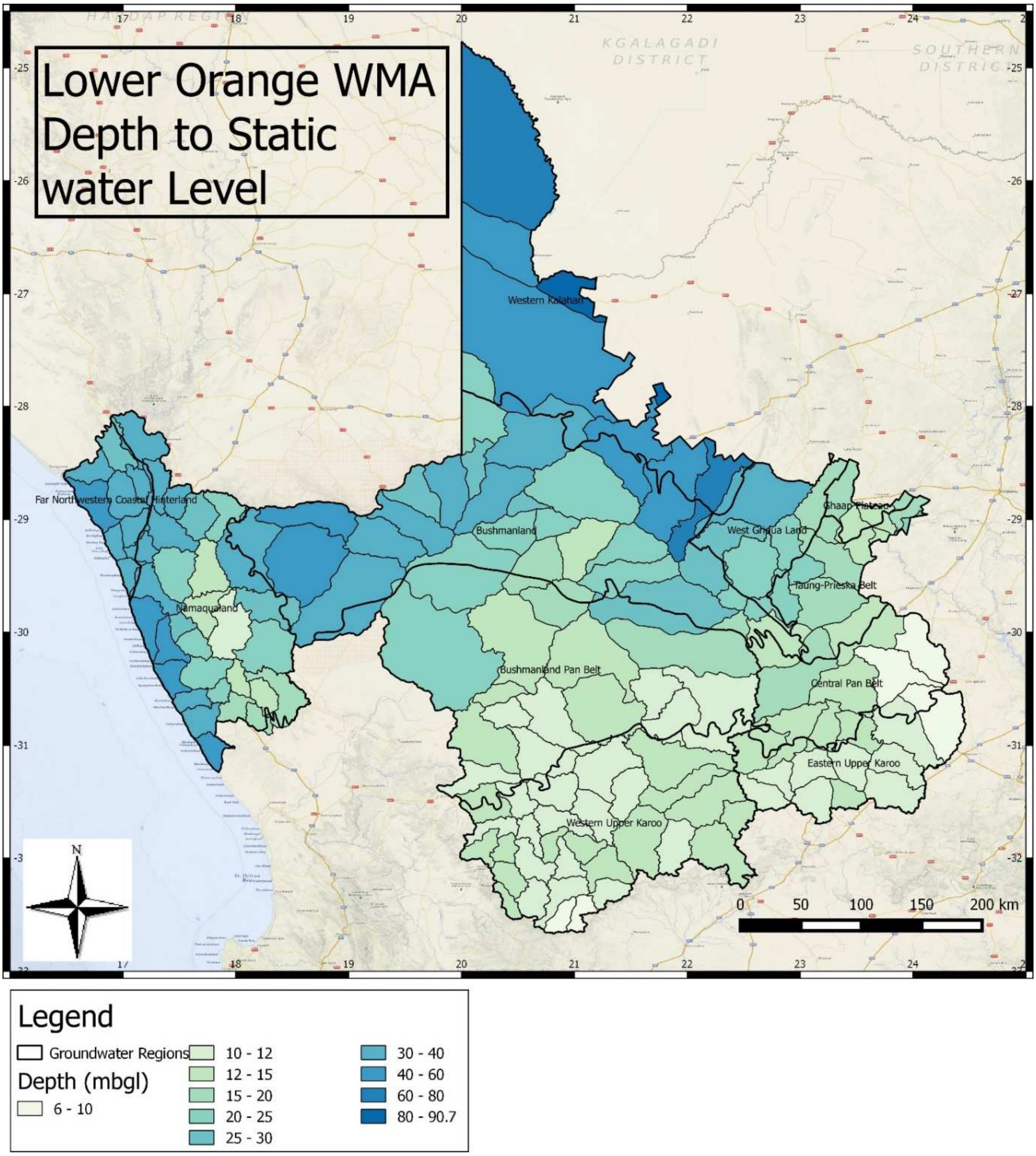


Figure 3.28 Depth to groundwater in the Lower Orange WMA

3.11.6 Groundwater quality

Groundwater quality was obtained from the DWS Water Management System (WMS) (ZQM database). For boreholes with a time series of analyses, the most recent water quality was used to avoid weighting analyses based on one borehole site. Data from 7829 boreholes are available and provide a good distribution across the WMA except in the Bushmanland Pan belt (Figure 3.29).

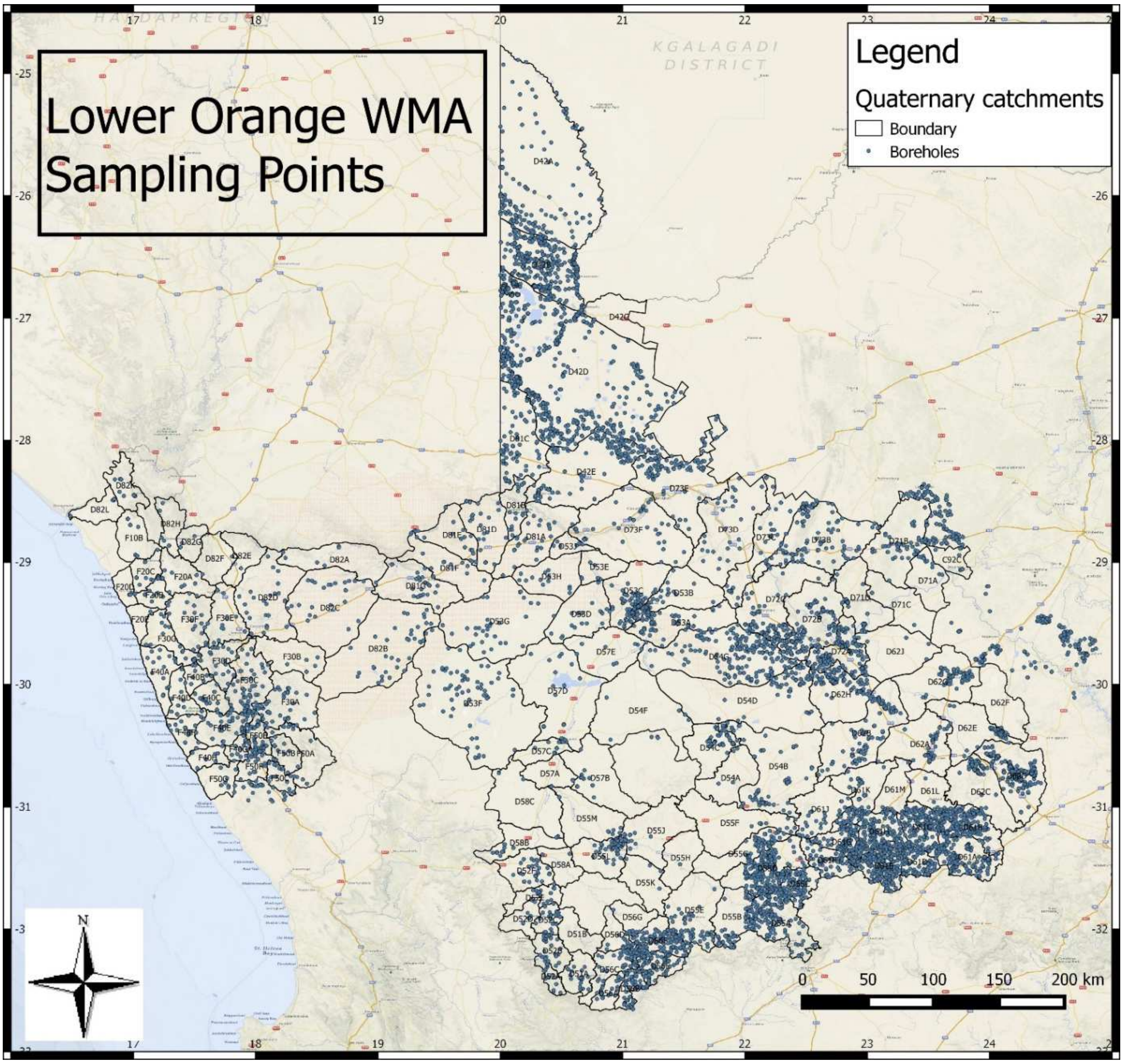


Figure 3.29 Location of groundwater quality sampling boreholes in the Lower Orange WMA

All hydrochemical data were collated and were assessed for potable use by using the Guidelines for Domestic Water Quality (DWAF, 1998) (Table 3.7).

Table 3-7 DWS Guidelines for Domestic Water Quality (DWAF, 1998)

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
pH		5.5 - 9.5	4.5-5.5 and 9.5-10	4-4.5 and 10-10.5	3-4 and 10.5-11	< 3 or > 11
Conductivity	mS/m	< 70	70 - 150	150 - 270	270 - 450	> 450
TDS	mg/l	< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
Total Hardness	$CaCO_3$	< 200	200 - 300	300 - 600	> 600	
Calcium	mg/l	< 80	80 - 150	150 - 300	> 300	
Copper	mg/l	< 1	1 - 1.3	1.3 - 2	2 - 15	> 15
Iron	mg/l	< 0.5	0.5 - 1	1 - 5	5 - 10	> 10
Magnesium	mg/l	< 70	70 - 100	100 - 200	200 - 400	> 400
Manganese	mg/l	< 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
Potassium	mg/l	< 25	25 - 50	50 - 100	100 - 500	> 500
Sodium	mg/l	< 100	100 - 200	200 - 400	400 - 1000	> 1000
Chloride	mg/l	< 100	100 - 200	200 - 600	600 - 1200	> 1200
Fluoride	mg/l	< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5	> 3.5
Nitrate NO_3 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Nitrite NO_2 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Orthophosphate (PO_4 as P)	mg/l	< 0.1	0.1 - 0.25	0.25 - 1	> 1	
Sulphate (SO_4)	mg/l	< 200	200 - 400	400 - 600	600 - 1000	> 1000
MPN *E. coli*	/100ml	0	0 - 1	1 - 10	10 - 100	> 100

Electrical Conductivity

The data indicates that Electrical Conductivity (EC) varies between 2 to over 20 000 mS/m (Figure 3.30), and that EC is highly variable, with boreholes of Class 0 located in close proximity to boreholes of Class 4. Pockets of Class 0 water are found south and southwest of Postmasburg in D71B and D73B, and in the Karoo north of Beaufort West. Groundwater is generally of Class 4 in coastal Namaqualand.

The distribution of Groundwater by water quality class in each Quaternary catchment is shown in Table 3.8.

The mean EC for each Quaternary and its water quality class is shown in Figure 3.31. Groundwater in the Bushmanland Panbelt, Bushmanland, the Western Kalahari, Namaqualand and the Far Northwestern Coastal Hinterland is generally of Class 3 or 4, Poor to Unacceptable. The fraction of boreholes which are Ideal and Good for potable water (Class 0 and 1), and Marginal water quality for emergency or short term potable use (Class 2) in each Quaternary is shown in Figure 3.32. The fraction of boreholes that are potable (potability index) declines to the west and north, reaching less than 0.1 in coastal Namaqualand.

Unexplainable high salinity exists in the Eastern Upper Karoo. This area should have lower salinity than the rest of the Karoo due to higher recharge rates and being located in a recharge zone at the edge of the Karoo Escarpment, hence flushing of the aquifer should be occurring, and the rocks are not of marine origin. This could indicate upwelling of deeper groundwater.

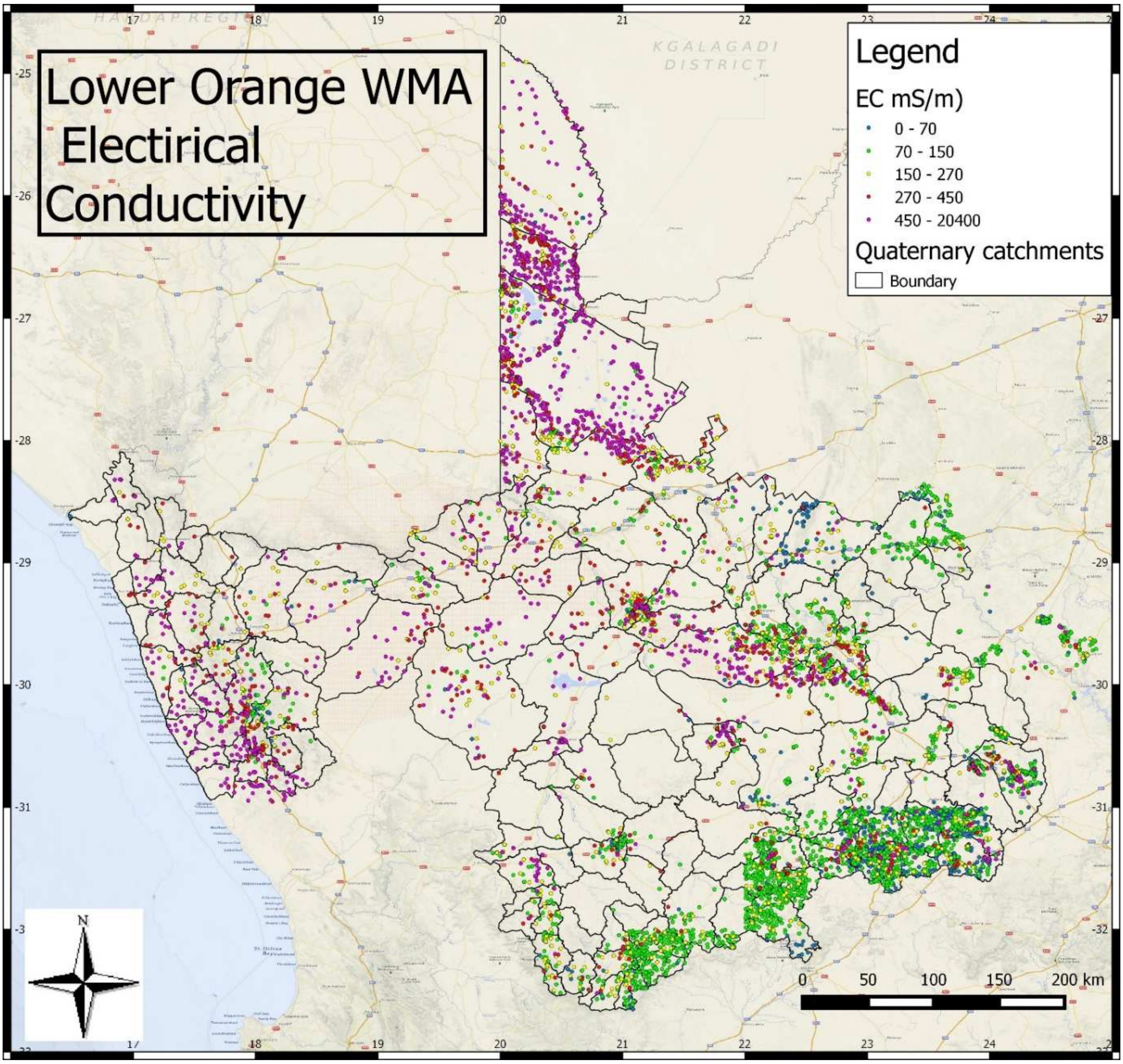


Figure 3.30 Electrical conductivity in boreholes situated in the Lower Orange WMA

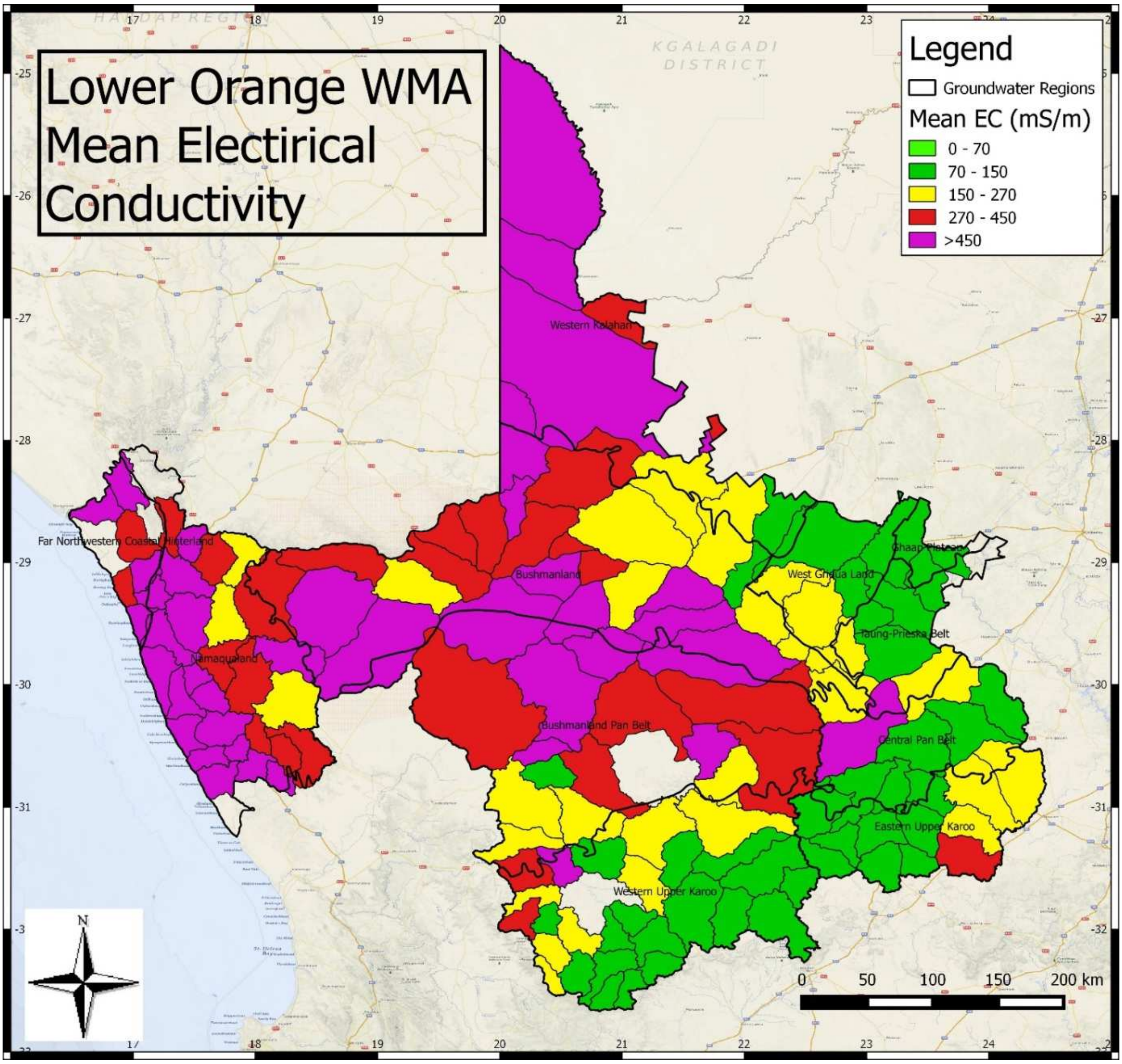


Figure 3.31 Mean Electrical conductivity by Quaternary in the Lower Orange WMA

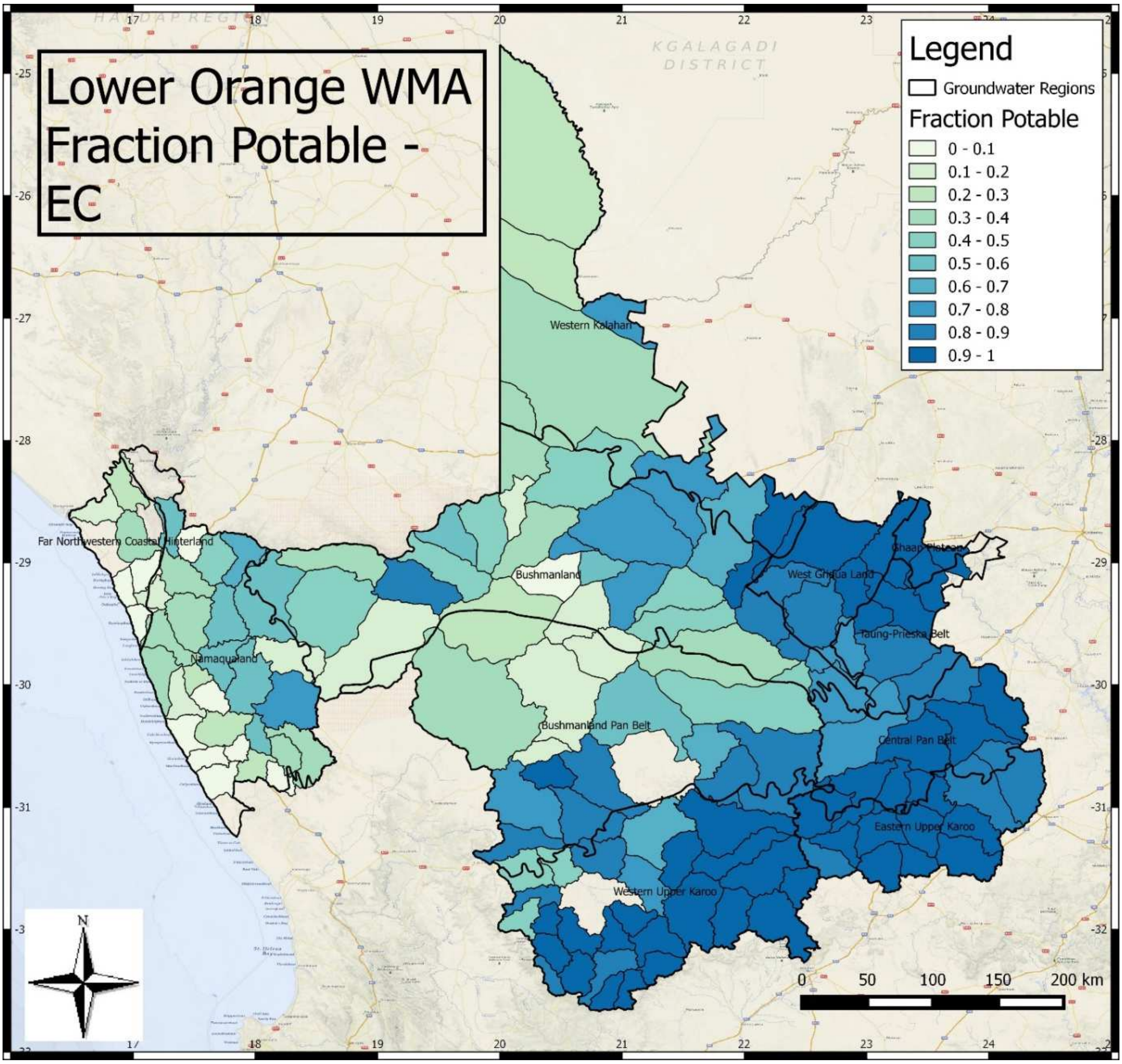


Figure 3.32 Fraction of potable boreholes by EC in the Lower Orange WMA

Table 3-8 EC Water quality distribution by Quaternary in the Lower Orange WMA

Quat	Percentile				N	Potable	Quat	Percentile				N	Potable	Quat	Percentile				N	Potable
	10	50	95	50*10%		Fraction		10	50	95	50*10%		Fraction		10	50	95	50*10%		Fraction
C51M							D56D	94.28	136.80	307.40	150.48	26	0.92	D81E	51.56	191.00	1183.30	210.10	23	0.57
C92B							D56E	76.90	96.60	141.90	106.26	86	1.00	D81F	75.48	241.00	>658	265.10	15	0.47
C92C	60.04	87.7	184.6	96.47	103	0.99	D56F	74.94	107.70	221.09	118.47	160	0.99	D81G	72.90	187.25	726.44	205.98	27	0.81
D33K							D56G	71.10	77.50	>136	85.25	9	1.00	D82A		376.5		414	6	0.33
D42A	200	596.3	2960.4	655.93	164	0.21	D56H							D82B	200.00	528.85	1610.40	581.74	36	0.17
D42B	171.4	455.2	1966.86	500.72	364	0.21	D56J							D82C	55.08	399.00	1956.42	438.90	23	0.43
D42C	147.2	238.4	>415	262.24	11	0.64	D57A		139.5		153.4	2	1.00	D82D	135.60	229.00	>624	251.90	18	0.56
D42D	101.14	400.3	3228.6	440.33	812	0.39	D57B	102.50	135.75	1424.00	149.33	16	0.81	D82E		218.5		240.35	8	0.75
D42E	101.31	300.95	934.29	331.045	127	0.42	D57C	201.50	1553.05	>4440	1708.36	12	0.17	D82F		273.5		301	2	0.50
D51A	47.98	122.10	355.80	134.31	22	0.91	D57D	258.80	634.00	6255.00	697.40	27	0.11	D82G		1093		1191.3	4	0.00
D51B		176		193.6	1	1.00	D57E	<167	320.55	>428	352.61	8	0.13	D82H		205.6		226.16	5	0.60
D51C							D58A		524		576	2	0.50	D82K	163.91	347.40	>993	382.14	12	0.25
D52A	70.40	155.20	335.50	170.72	19	0.89	D58B	94.98	198.00	590.80	217.80	14	0.86	D82L		630		693	5	0.20
D52B	97.55	148.20	431.57	163.02	26	0.92	D58C	<89	106.7	>237	117	4	0.75	F10A						
D52C	86.20	126.50	297.06	139.15	22	0.95	D61A	52.93	86.25	1897.32	94.88	152	0.91	F10B	174.32	324.00	>651	356.40	8	0.38
D52D	122.00	286.00	>406	314.60	8	0.50	D61B	55.26	75.90	284.19	83.49	183	0.95	F10C						
D52E	88.80	142.00	>474	156.20	13	0.85	D61C	59.30	75.90	222.82	83.49	153	0.97	F20A	192.90	274.00	>1031	301.40	10	0.40
D52F	74.90	190.00	1520	209.00	27	0.48	D61D	55.66	82.00	411.80	90.20	87	0.94	F20B	188.20	688.00	>812	756.80	13	0.15
D53A	82.24	276.30	1431.54	303.93	70	0.49	D61E	50.47	88.45	285.03	97.30	300	0.94	F20C	382.43	891.30	>2656	980.43	8	0.00
D53B	90.46	331.40	1298.82	364.54	84	0.44	D61F	61.50	97.90	492.80	107.69	60	0.88	F20D		362.9		399.19	3	0.00
D53C	71.18	167.90	878.40	184.69	127	0.69	D61G	60.87	89.85	480.49	98.84	162	0.92	F20E		1133		1246	1	0.00
D53D	95.40	376.00	>1409	413.60	17	0.18	D61H	54.64	74.70	321.28	82.17	135	0.94	F30A	52.44	149.00	886.80	163.90	42	0.79
D53E	<107	173.3	>351	190.63	7	0.57	D61J	68.14	103.05	238.55	113.36	26	1.00	F30B		483		531.3	6	0.17
D53F	135.37	344.00	974.95	378.40	59	0.32	D61K	58.00	82.10	459.50	90.31	71	0.93	F30C	64.09	209.10	846.60	230.01	67	0.55
D53G	191.05	522.70	1137.25	574.97	34	0.21	D61L	55.60	65.00	385.50	71.50	21	0.95	F30D	100.63	238.50	1048.03	262.35	20	0.55
D53H	236.60	406.40	>900	447.04	13	0.08	D61M	53.70	76.20	>101	83.82	11	1.00	F30E	72.06	227.00	>508	249.70	14	0.57
D53J	<86	213.5	>570	234.85	7	0.71	D62A	70.24	88.80	237.94	97.68	46	0.98	F30F	103.52	321.00	1046.30	353.10	19	0.26
D54A	<91	151	>256	166.1	5	0.80	D62B	88.35	148.20	1037.50	163.02	120	0.78	F30G	85.78	303.00	3171.47	333.30	25	0.36
D54B	58.15	96.85	2888.00	106.54	86	0.81	D62C	68.15	141.45	382.69	155.60	104	0.86	F40A	125.96	286.10	>797	314.71	14	0.36
D54C	111.36	185.00	3363.53	203.50	61	0.64	D62D	67.50	115.50	553.60	127.05	253	0.85	F40B	77.00	448.00	>911	492.80	9	0.22
D54D	105.70	306.10	1190.00	336.71	57	0.47	D62E	69.94	93.60	217.80	102.96	62	0.98	F40C	229.15	641.50	>960	705.65	14	0.07
D54E							D62F		87.8		118.7	3	1.00	F40D	53.13	725.00	>845	797.50	10	0.20
D54F	<48	244	>411	268.4	5	0.60	D62G	79.72	124.95	522.67	137.45	71	0.87	F40E	69.65	589.20	1520.00	648.12	42	0.21
D54G	115.30	365.40	1268.54	401.94	200	0.38	D62H	90.88	180.50	634.94	198.55	105	0.70	F40F	487.80	926.00	6493.10	1018.60	19	0.00
D54H							D62J	55.00	78.90	>155	86.79	9	0.89	F40G	588.90	871.30	>1293	958.43	14	0.00
D54J							D71A	72.60	86.70	>110	95.37	11	1.00	F40H	1046			1150	7	0.00
D55A	59.36	93.15	183.51	102.47	162	1.00	D71B	48.46	85.50	125.56	94.05	61	0.98	F50A	46.65	313.75	>832	345.13	15	0.33

Quat	Percentile				N	Potable	Quat	Percentile				N	Potable	Quat	Percentile				N	Potable
	10	50	95	50*10%		Fraction		10	50	95	50*10%		Fraction		10	50	95	50*10%		Fraction
D55B	70.82	82.80	186.66	91.08	60	1.00	D71C		46.8		51.48	2	1.00	F50B	22.00	326.00	>531	358.60	10	0.40
D55C	79.40	114.40	206.28	125.84	112	0.98	D71D	67.32	128.80	354.28	141.68	36	0.92	F50C	194.16	655.50	>875	721.05	13	0.08
D55D	75.84	104.50	445.09	114.95	222	0.91	D72A	86.83	171.90	510.41	189.09	142	0.76	F50D	431.52	835.90	1468.66	919.49	24	0.00
D55E	73.52	105.10	267.12	115.61	58	0.97	D72B	79.32	126.80	487.40	139.48	154	0.85	F50E	50.17	226.10	674.50	248.71	52	0.60
D55F	86.36	162.00	>231	178.20	10	0.90	D72C	79.40	127.50	420.63	140.25	116	0.90	F50F	170.79	574.50	1533.00	631.95	36	0.22
D55G	72.60	105.60	328.43	116.16	62	0.92	D73B	5.84	55.65	541.85	61.22	102	0.92	F50G		622		684	7	0.00
D55H		90		99	1	1.00	D73C	5.45	41.50	272.22	45.65	44	0.95	F60A						
D55J	47.19	108.50	>359	119.35	12	0.67	D73D	60.85	187.70	982.95	206.47	29	0.69							
D55K	<99	174.6	>233	192.06	4	0.75	D73E	90.68	195.00	709.86	214.50	91	0.69							
D55L	60.34	73.90	367.70	81.29	53	0.89	D73F	88.30	181.00	473.20	199.10	44	0.73							
D55M	96.00	173.60	>275	190.96	8	0.75	D81A	98.55	339.50	1352.75	373.45	24	0.33							
D56A	63.25	125.20	>189	137.72	15	1.00	D81B	193.20	474.00	1077.90	521.40	17	0.18							
D56B	66.80	96.00	213.34	105.60	79	0.97	D81C	156.46	407.00	3181.19	447.70	82	0.38							
D56C	74.99	112.90	423.54	124.19	52	0.88	D81D	110.45	372.00	912.15	409.20	20	0.45							

Table 3-9 Nitrate water class distribution by Quaternary in the Lower Orange WMA

Quat	Percentile				Potable	Quat	Percentile				Potable	Quat	Percentile				Potable
	10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction
C92C	0.12	13.47	151.38	14.81	0.57	D56C	0.06	7.73	39.07	8.50	0.80	D73D	1.39	8.23	86.95	9.05	0.63
D42A	0.30	6.79	60.73	7.47	0.74	D56D	0.07	9.29	43.72	10.21	0.85	D73E	0.37	5.44	65.14	5.98	0.73
D42B	0.61	7.91	44.96	8.70	0.78	D56E	0.25	6.49	44.75	7.13	0.81	D73F	0.29	11.28	159.79	12.41	0.67
D42C	0.05	13.00	>25	14.30	0.82	D56F	0.37	7.00	39.43	7.70	0.80	D81A	0.13	4.31	88.91	4.74	0.80
D42D	0.64	5.91	49.90	6.50	0.85	D56G	3.91	20.32	>34	22.35	0.44	D81B	0.22	10.03	>78	11.03	0.59
D42E	0.24	5.46	34.77	6.00	0.84	D57A		0.62		0.68	1	D81C	0.11	3.98	58.49	4.38	0.81
D51A	0.07	12.03	306.55	13.24	0.57	D57B	0.01	2.65	>11	2.92	0.92	D81D	0.17	3.86	113.99	4.24	0.79
D51B		10.64		11.7	1.00	D57C	1.73	10.40	>28	11.43	0.67	D81E	0.06	10.39	115.38	11.43	0.68
D52A	0.04	3.50	>32	3.85	0.82	D57D	0.04	10.21	37.97	11.23	0.81	D81F	0.14	8.57	>22.6	9.43	0.87
D52B	0.02	9.82	96.70	10.80	0.68	D57E	<0.37	5.07	>27	5.58	0.88	D81G	0.04	6.79	59.12	7.47	0.81
D52C	0.35	4.65	63.12	5.11	0.82	D58A		4.67		5.14	1	D82A	<1.39	5.49	>19	6.04	0.83
D52D		10.17	>26	11.19	0.71	D58B	0.06	12.92	>26.3	14.21	0.54	D82B	0.06	5.40	68.95	5.93	0.86
D52E	4.55	23.77	>65	26.14	0.42	D58C		45.67		50.23	0.25	D82C	0.02	1.39	206.57	1.53	0.74
D52F	0.04	4.73	125.88	5.20	0.85	D61A	0.91	5.86	25.80	6.45	0.86	D82D	0.04	4.39	>51	4.83	0.76
D53A	0.56	7.49	60.36	8.24	0.80	D61B	0.61	4.97	20.76	5.47	0.93	D82E	<0.11	4.91	>76.5	5.4	0.67

Quat	Percentile				Potable	Quat	Percentile				Potable	Quat	Percentile				Potable
	10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction
D53B	0.50	6.33	55.29	6.96	0.77	D61C	0.74	5.48	20.12	6.03	0.95	D82F		4.37		4.81	1
D53C	0.69	7.00	40.68	7.70	0.80	D61D	0.66	4.99	15.99	5.49	0.97	D82G	>14	18.21	>22	20.06	0.5
D53D	0.40	9.26	>75	10.19	0.65	D61E	0.45	7.33	32.89	8.06	0.81	D82H	<2.6	3.17	>6.4	3.49	1
D53E		8.43	>26	9.27	0.71	D61F	0.60	9.36	209.18	10.29	0.60	D82K	0.07	3.96	>12.4	4.36	1.00
D53F	0.12	18.65	153.99	20.52	0.55	D61G	0.38	5.97	31.88	6.57	0.87	D82L	<4	20.82	>26	22.9	0.4
D53G	0.28	11.30	146.62	12.43	0.59	D61H	0.20	5.40	31.09	5.94	0.92	F10B	<6.4	8.48	>88	9.33	0.75
D53H	0.03	3.24	>8	3.56	1.00	D61J	0.03	6.12	58.02	6.73	0.75	F20A	0.08	5.45	>18.5	6.00	0.90
D53J	<1.65	10.48	>30	11.53	0.57	D61K	0.35	7.01	21.74	7.71	0.92	F20B	0.01	7.90	>92	8.69	0.62
D54A	<1.69!	1.81	>18.5	1.99	0.80	D61L	0.02	3.53	33.61	3.88	0.86	F20C	<0.87	7.16	>10	7.87	1
D54B	0.26	7.71	49.60	8.48	0.82	D61M	0.09	5.22	>15.2	5.74	0.91	F20D		18.74		20.62	0.67
D54C	0.08	16.29	117.79	17.92	0.53	D62A	0.06	5.86	22.53	6.44	0.94	F20E		12.2			1
D54D	0.11	4.34	27.62	4.77	0.89	D62B	0.19	3.92	24.85	4.31	0.92	F30A	0.29	5.38	77.04	5.92	0.81
D54F		0.13		0.14	1	D62C	0.26	8.34	46.99	9.17	0.80	F30B	<2	20.12	>36	22.13	0.5
D54G	0.42	6.11	41.81	6.72	0.86	D62D	0.32	10.10	66.68	11.10	0.66	F30C	0.39	6.85	80.72	7.54	0.75
D55A	0.10	8.82	64.14	9.70	0.70	D62E	1.03	10.82	50.08	11.90	0.74	F30D	0.11	8.96	>36	9.85	0.76
D55B	0.41	5.59	27.51	6.15	0.89	D62F		20.54		22.59	0.33	F30E	0.02	3.23	>14.8	3.55	0.92
D55C	0.37	6.29	70.48	6.92	0.79	D62G	0.07	8.20	62.39	9.02	0.71	F30F	0.02	9.14	126.63	10.05	0.68
D55D	0.36	6.25	43.34	6.88	0.76	D62H	0.22	4.89	35.99	5.38	0.90	F30G	0.26	12.08	108.48	13.29	0.52
D55E	0.99	9.60	49.53	10.56	0.80	D62J	<1.08	1.64	>5.1	1.80	1.00	F40A	0.07	8.43	>79	9.27	0.57
D55F	0.01	20.59	>63	22.65	0.50	D71A	0.57	6.95	>55	7.65	0.73	F40B	<1.4	7.44	>34	8.18	0.6
D55G	0.13	7.38	48.56	8.12	0.75	D71B	0.44	16.13	168.52	17.74	0.56	F40C	<2.18	4.46	>5	4.9	1
D55H		0.59				D71C		10.87		11.96	1	F40D	<17	35.92	>36	39.51	0.4
D55J	0.04	12.16	>37	13.38	0.67	D71D	0.41	3.86	20.89	4.24	0.94	F40E	0.11	5.48	43.03	6.03	0.89
D55K		2.06		2.27	0.67	D72A	0.23	4.66	24.75	5.13	0.94	F40F	0.71	14.35	>49	15.79	0.67
D55L	0.16	8.78	59.00	9.66	0.67	D72B	0.67	4.56	22.38	5.02	0.93	F40G	0.02	3.65	>18.5	4.02	0.93
D55M	<0.39!	1.15	>5.8	1.26	1.00	D72C	0.21	4.61	32.36	5.07	0.87	F40H		6.23		6.85	1
D56A	0.19	2.84	>79	3.12	0.71	D73B	0.18	8.97	136.45	9.87	0.69	F50A	0.01	2.90	>13.7	3.18	1.00
D56B	0.29	7.49	43.47	8.24	0.79	D73C	0.25	8.92	105.47	9.81	0.71	F50B	0.00	0.46	>2.7	0.51	1.00
												F50C	0.04	1.74	>7.29	1.91	1.00
												F50D	0.11	4.42	21.24	4.86	0.96
												F50E	0.30	4.83	68.76	5.31	0.88
												F50F	0.23	3.53	25.97	3.88	0.91

Quat	Percentile				Potable	Quat	Percentile				Potable	Quat	Percentile				Potable
	10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction
												F50G	<0.13	1.61	>2.26	1.77	1

Table 3-10 Fluoride water class distribution by Quaternary in the Lower Orange WMA

Quat	Percentile				Potable	Quat	Percentile				Potable	Quat	Percentile				Potable
	10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction
C92C	0.65	2.02	7.31	2.23	0.31	D56E	0.52	1.07	3.99	1.17	0.72	D81A	0.53	1.66	16.14	1.83	0.33
D42A	0.43	1.34	4.50	1.47	0.60	D56F	0.45	1.08	3.48	1.19	0.72	D81B	0.22	1.24	>4.9	1.36	0.53
D42B	0.48	1.50	6.21	1.65	0.50	D56G	0.05	0.55	>1.52	0.61	0.78	D81C	0.42	1.53	10.63	1.68	0.50
D42C	0.42	1.86	>5.9	2.05	0.36	D57A		2.61		2.87	0.5	D81D	0.55	1.66	18.07	1.82	0.40
D42D	0.42	1.36	6.00	1.49	0.54	D57B	0.25	1.17	>4.7	1.29	0.53	D81E	0.49	2.47	9.10	2.72	0.32
D42E	0.32	0.89	4.52	0.98	0.70	D57C	0.47	1.13	>4.55	1.24	0.67	D81F	0.29	1.29	>5.7	1.42	0.60
D51A	0.57	2.17	4.31	2.38	0.30	D57D	0.50	1.83	5.56	2.01	0.50	D81G	0.39	1.85	4.07	2.04	0.44
D51B		0.89		0.98	1	D57E	<0.65	0.97	>1.4	1.07	0.83	D82A	<1.24	1.85	>2,5	2.04	0.5
D52A	0.53	0.82	>6.6	0.90	0.67	D58A		1.85		2.03	0	D82B	0.34	1.13	20.71	1.24	0.73
D52B	0.53	1.47	5.00	1.61	0.50	D58B	0.38	2.27	>6.3	2.50	0.31	D82C	0.59	1.53	19.26	1.68	0.48
D52C	0.56	1.60	4.83	1.76	0.48	D58C	<1.36	1.43	>1.5	1.57	0.5	D82D	0.24	2.37	>12	2.61	0.39
D52D	<0.55	1.41	>6.3	1.55	0.5	D61A	0.41	1.08	4.58	1.19	0.67	D82E	<2.2	2.51	>3.2	2.76	0
D52E	0.33	0.73	>2.88	0.80	0.69	D61B	0.36	0.95	4.00	1.05	0.73	D82F		3.16		3.48	0
D52F	0.70	1.52	4.44	1.67	0.48	D61C	0.38	0.95	4.90	1.04	0.72	D82G		1.41		1.55	0.5
D53A	0.40	1.15	6.61	1.26	0.65	D61D	0.46	0.97	3.95	1.06	0.71	D82H	<0.61	0.7	>0.7	0.77	1
D53B	0.52	1.41	6.29	1.55	0.51	D61E	0.39	1.22	4.41	1.34	0.59	D82K	0.27	1.35	>21.	1.48	0.58
D53C	0.61	1.26	5.85	1.38	0.59	D61F	0.40	1.91	5.91	2.10	0.44	D82L	<0.6	1.01	>1.29	1.11	0.8
D53D	0.41	1.21	>4.54	1.33	0.60	D61G	0.42	1.28	10.00	1.41	0.54	F10B	<0.7	1.74	>3.2	1.91	0.38
D53E	<0.92	1.78	>7.25	1.96	0.43	D61H	0.41	0.99	4.02	1.09	0.72	F20A	0.32	2.10	>4.88	2.30	0.40
D53F	1.10	2.84	18.09	3.12	0.13	D61J	0.46	2.00	10.87	2.19	0.38	F20B	0.48	1.06	>2.65	1.17	0.70
D53G	0.31	2.45	18.43	2.70	0.39	D61K	0.38	0.95	3.47	1.05	0.83	F20C	<0.8	1.88	>3.5	2.07	0.43
D53H	0.50	1.00	>4	1.10	0.69	D61L	0.37	0.74	3.61	0.81	0.85	F20D		2.05		2.26	0.33
D53J	<0.96	1.35	>2.8	1.49	0.57	D61M	0.36	0.85	>2.15	0.94	0.80	F20E		1.58		1.74	0
D54A	<1.69	2.38	>3.6	2.62	0.20	D62A	0.52	1.30	6.41	1.43	0.61	F30A	0.46	1.47	19.12	1.61	0.55
D54B	0.59	1.64	4.30	1.80	0.48	D62B	0.40	1.01	3.15	1.11	0.73	F30B	<1.2	1.94	>2.1	2.13	0.33
D54C	0.36	1.57	11.54	1.72	0.45	D62C	0.42	1.10	4.80	1.21	0.64	F30C	0.50	1.26	7.95	1.39	0.56

Quat	Percentile				Potable	Quat	Percentile				Potable	Quat	Percentile				Potable
	10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction		10	50	95	50*10%	Fraction
D54D	0.41	1.00	3.34	1.10	0.65	D62D	0.48	1.71	6.32	1.88	0.47	F30D	0.28	2.63	11.94	2.90	0.30
D54F	<1.44	1.65	>2.1	1.82	0.40	D62E	0.40	1.51	6.85	1.66	0.49	F30E	0.83	2.27	>7.2	2.50	0.31
D54G	0.46	1.12	4.37	1.23	0.66	D62F		0.6		0.66	0.67	F30F	0.98	2.20	>4.1	2.42	0.33
D55A	0.52	1.46	6.00	1.61	0.50	D62G	0.57	2.25	6.61	2.48	0.36	F30G	0.52	2.25	9.67	2.48	0.33
D55B	0.74	1.34	4.75	1.47	0.60	D62H	0.37	1.00	3.47	1.10	0.74	F40A	0.92	2.17	>2.9	2.39	0.29
D55C	0.59	1.30	6.83	1.43	0.58	D62J	0.34	1.14	>1.75	1.25	0.78	F40B	1.02	2.53	>3.95	2.78	0.11
D55D	0.57	1.50	6.48	1.65	0.50	D71A	0.17	2.79	>6.78	3.07	0.36	F40C	0.23	1.66	>5.32	1.82	0.38
D55E	0.31	0.98	4.99	1.08	0.72	D71B	0.83	2.02	8.50	2.22	0.36	F40D	0.13	2.87	>7.91	3.15	0.20
D55F	1.05	3.88	>12.14	4.27	0.20	D71C		1.51		1.66	0.5	F40E	0.32	0.87	3.44	0.96	0.74
D55G	0.56	1.41	7.06	1.55	0.56	D71D	0.59	1.18	3.78	1.30	0.68	F40F	0.32	2.03	15.67	2.23	0.47
D55H		0.76		0.84	1.00	D72A	0.44	1.06	4.59	1.17	0.72	F40G	0.25	0.81	>2.45	0.89	0.86
D55J	0.64	1.76	>6.2	1.93	0.33	D72B	0.36	1.14	3.93	1.25	0.63	F40H	<0.5	0.8	>1.2	0.88	0.86
D55K		0.76		0.84	1	D72C	0.52	1.13	5.75	1.24	0.67	F50A	0.31	0.70	>3.9	0.77	0.80
D55L	0.53	1.50	3.40	1.65	0.50	D73B	0.76	1.99	5.60	2.19	0.39	F50B	0.40	1.14	>2.45	1.25	0.56
D55M	<1.31	1.64	>3.4	1.8	0.29	D73C	0.32	1.93	20.02	2.12	0.45	F50C	0.30	0.74	>1.64	0.81	0.85
D56A	0.90	2.25	>5.5	2.48	0.33	D73D	0.72	1.84	22.29	2.03	0.33	F50D	0.22	0.70	3.47	0.77	0.90
D56B	0.63	1.35	3.97	1.49	0.59	D73E	0.43	1.01	5.08	1.11	0.60	F50E	0.21	0.99	6.79	1.08	0.77
D56C	0.48	1.18	6.35	1.30	0.59	D73F	0.50	1.51	7.60	1.66	0.50	F50F	0.32	0.87	19.85	0.96	0.85
D56D	0.48	1.37	3.82	1.51	0.54							F50G	<0.67	0.85	>1.3	0.93	0.83

Nitrates

The concentration of nitrates by water quality class and quaternary catchment is shown in Table 3.9. Figure 3.33 shows the faction of boreholes with potable groundwater for nitrates in each quaternary catchment. Elevated nitrates are found throughout the study area. Groundwater in the western Kalahari, Bushmanland and Namaqualand show elevated nitrates with only 50-70% of boreholes yielding potable water.

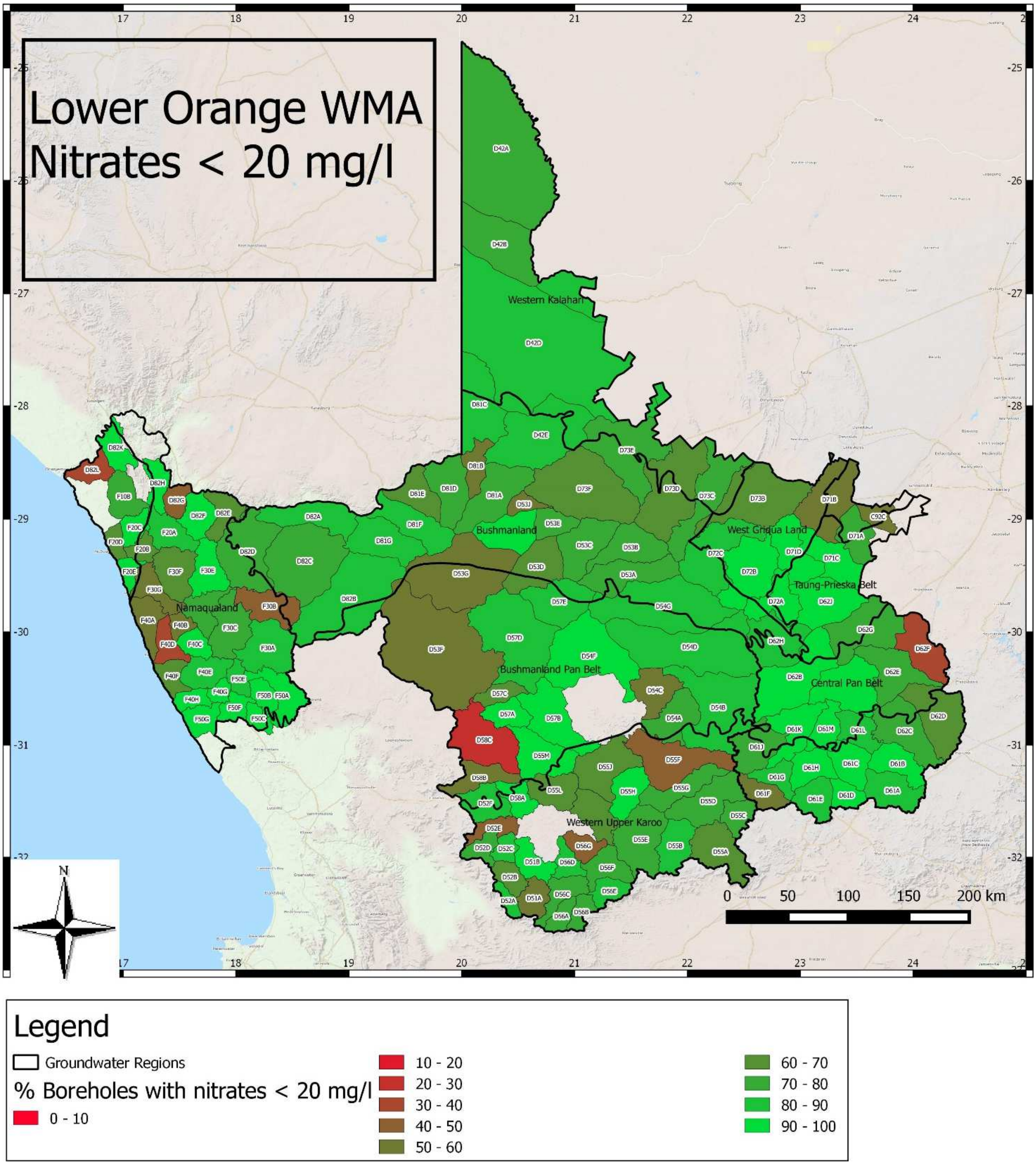


Figure 3.33 Fraction of potable boreholes by nitrates in the Lower Orange WMA

Fluorides

The concentration of Fluorides by water quality class and quaternary catchment is shown in Table 3.10. Figure 3.34 shows the faction of boreholes with potable groundwater for fluorides in each quaternary catchment. Groundwater in the western Kalahari, Bushmanland, the Bushmanland Pan

Belt and Namaqualand show elevated fluorides, with less than 50% of boreholes yielding potable water.

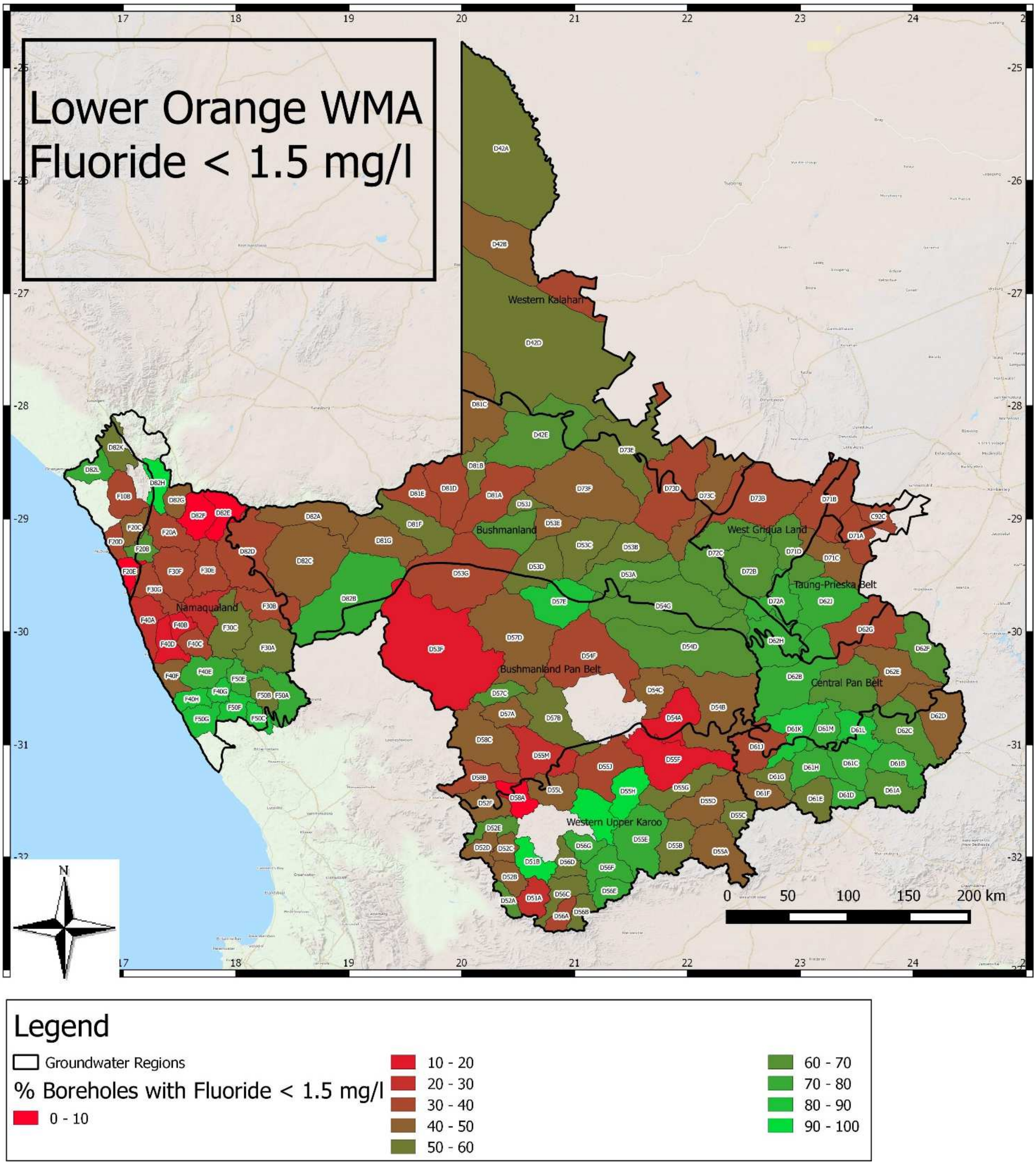


Figure 3.34 Fraction of potable boreholes by fluoride in the Lower Orange WMA

pH

The Water Quality Range for Ideal or Good quality water pH is 4.5-10 (DWAF, 1998). Marginal quality extends the pH range down to 4 and to 10.5Below 4 toxic effects associated with dissolved metals are likely to occur. Above 9, the probability of toxic effects associated with deprotonated species increases sharply. The areas of occurrence of acidic waters (pH <6) is shown in Figure 3.35, and that of very basic water (pH>9) in Figure 3.36. Acid waters are rare and where present, their probability of occurrence is low (<10%). Basic ground water is found in the Bushmanland Pan belt, Taung-Prieska, and the Western Kalahari.

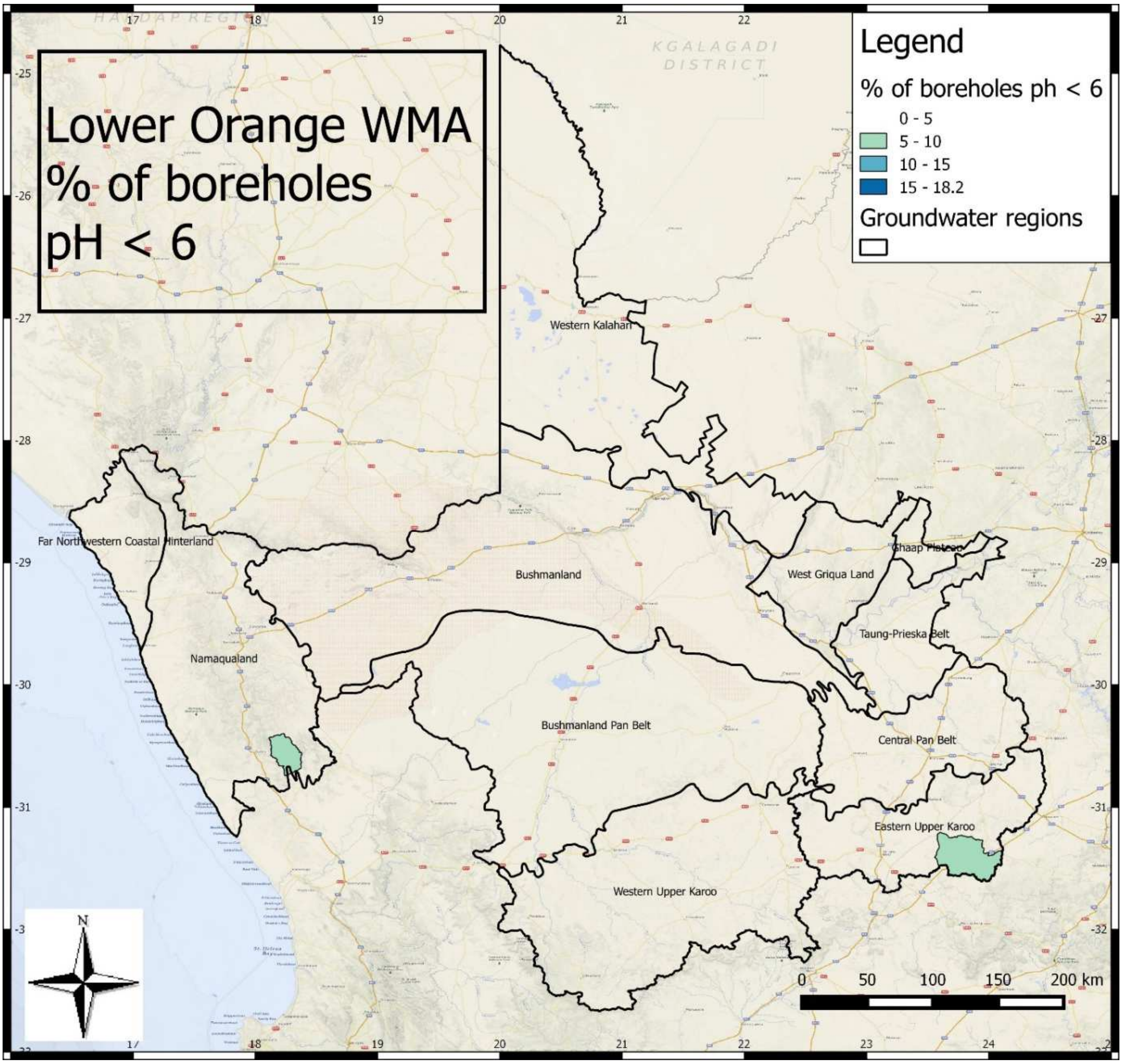


Figure 3.35 Fraction of boreholes with pH < 6 in the Lower Orange WMA

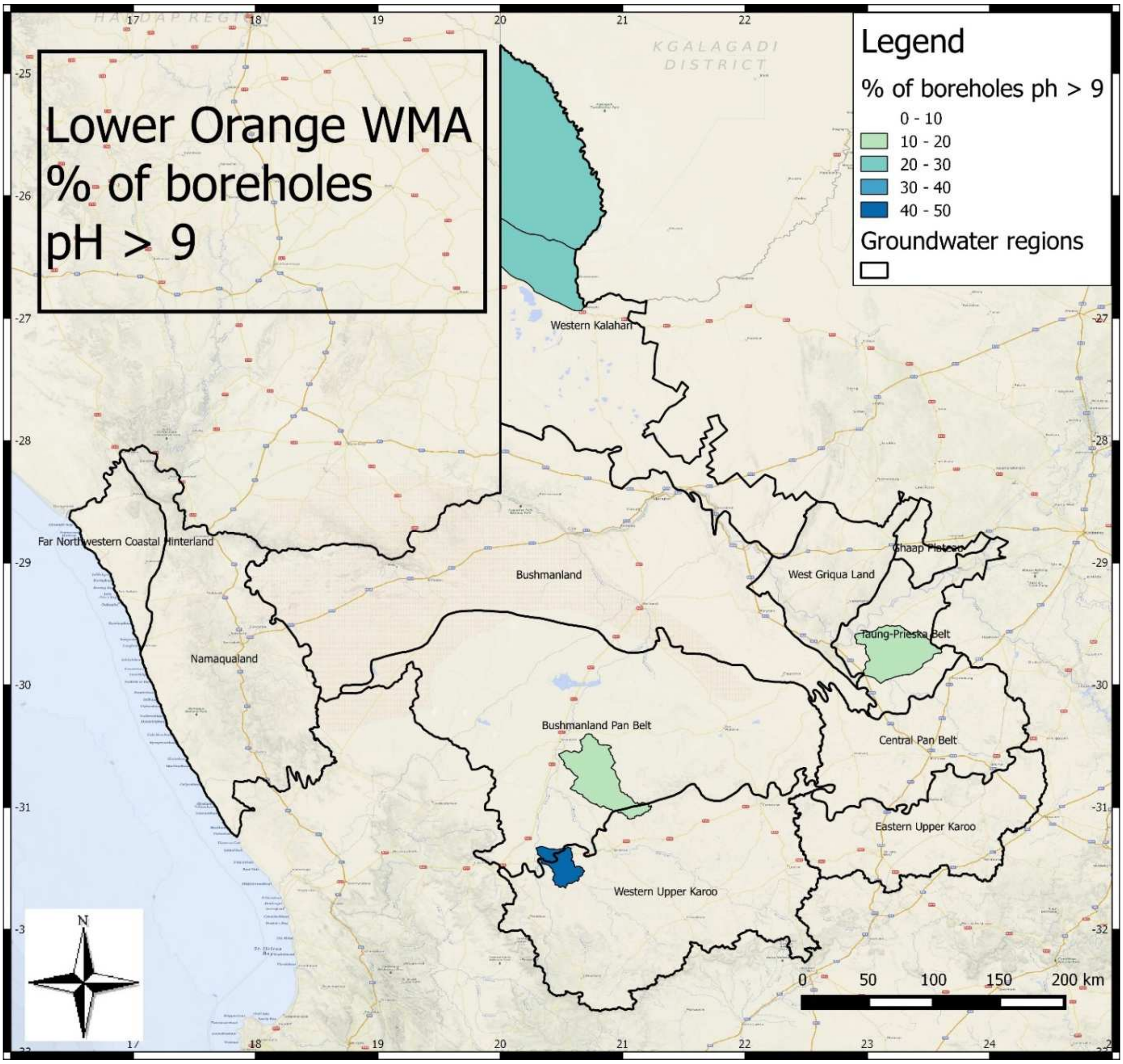


Figure 3.36 Fraction of boreholes with pH >9 in the Lower Orange WMA

Metals

Groundwater data from the ZQM database for Inductively Coupled Plasma (ICP) metal scans for trace metals were also examined to evaluate trace metals. The following metals were found of significance: Arsenic (As), Molybdenum (Mo) and Cadmium (Cd).

Arsenic

There are about 24 As-bearing minerals commonly found in hydrothermal veins, ore deposits. Most primary As minerals are sulphides, of which arsenopyrite is the most common. Most Arsenic bearing minerals occur in sulphide rich mineralised areas in close association with Cd, Pb, Ag, Au, Sb, P, W and Mo. Arsenic is one of a suite of incompatible elements that do not fit easily into the lattices of common rock-forming minerals. It is common in geothermal springs that leach continental rocks. Because arsenic is an incompatible element, it accumulates in differentiated magmas, and commonly found at higher concentrations in volcanic rocks of intermediate (andesites) to felsic (rhyolites) composition than in mafic (basaltic/doleritic) rocks. It is only found in sedimentary rocks, such as the Karoo, where argillaceous rocks with sulphide mineralisation under reducing conditions, such as black carbonaceous shales.

The Target Water Quality Guideline Range is 0 - 10 ug/l and should never exceed 200 ug/l, which would result in serious health risk (DWAF, 2006b).

The frequency of As occurrence over 50 ug/l is shown in Figure 3.37. The high concentration of As across the Bushmanland Pan belt and the Central Pan Belt coincides with the outcrop of carbonaceous Ecca shale (Figure 3.20), where it would be expected. The presence of significant occurrences of As in the eastern Western Upper Karroo and the Eastern Upper Karroo cannot be explained by the sandstone and mudstone geology, which does not contain As minerals. However, AS could be an indicator of upwelling of deeper groundwater from the underlying carbonaceous shales. **This is potentially of concern as it suggests that groundwater from the carbonaceous shales potentially targeted for fracking could be upwelling into the shallow aquifer, and conduits between the deep and shallow groundwater could exist.**

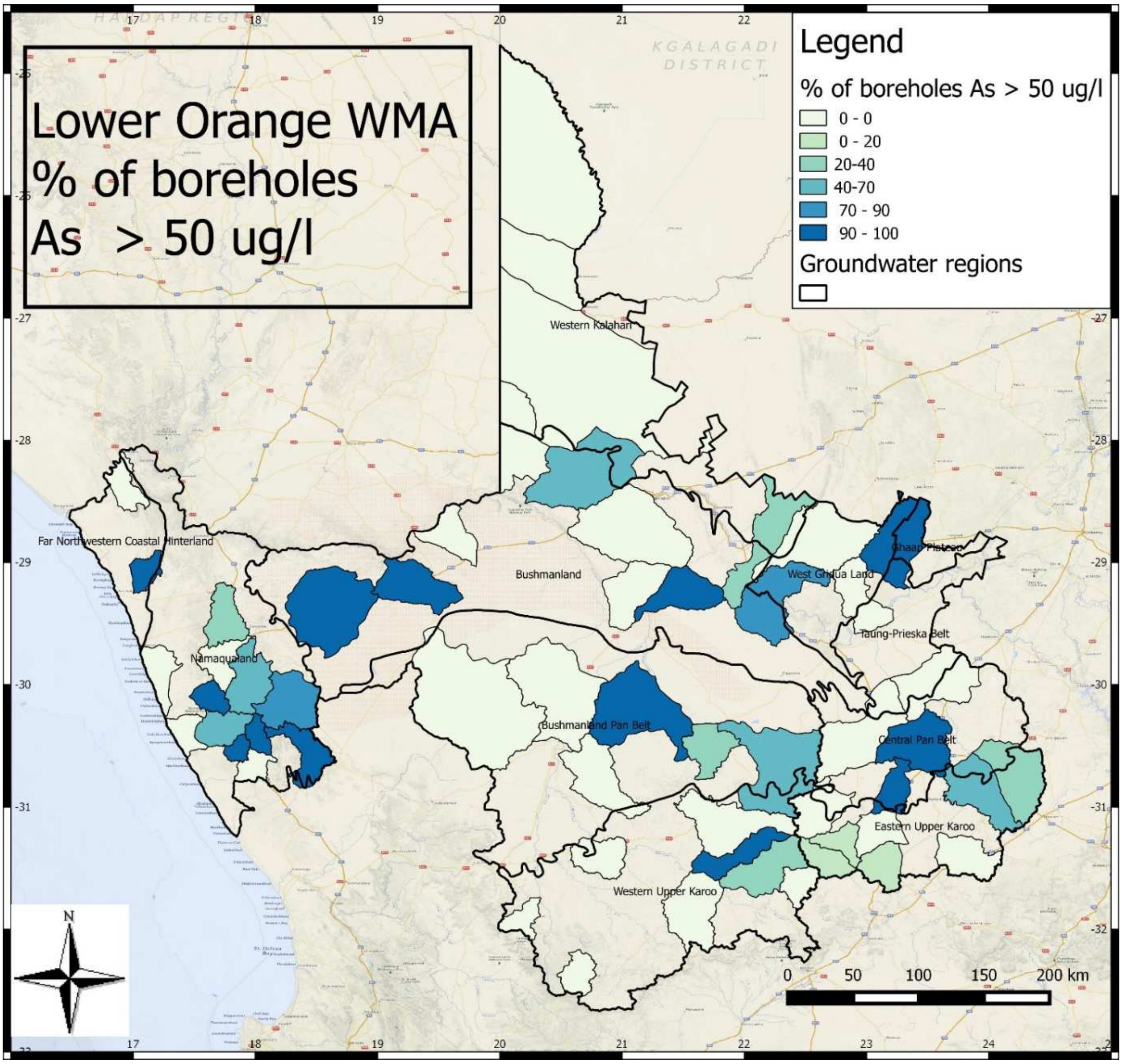


Figure 3.37 Fraction of boreholes with As >50 ug/l in the Lower Orange WMA

Molybdenum

Molybdenum is a strongly chalcophile or siderophile metallic element forming several minerals but is more widely present at trace levels in association with organic matter and sedimentary sulphide minerals, notably in black shale.

Mo behaves incompatibly and is only sparingly incorporated in major rock-forming silicates. In sediments, Mo tends to follow Cu in its behaviour and is strongly complexed by organic matter. Black shale is therefore, enriched in Mo. Unlike most metals, Mo is mobile under alkaline conditions, and finds particular application in reconnaissance exploration in arid environments. Consequently, Mo can be an indicator of groundwaters in contact with carbonaceous shales. Figure 3.38 shows the frequency of occurrence of Mo above 0.07 mg/l. The presence of significant occurrence of Mo in the Western and Eastern Upper Karoo, without any geological sources, suggests that there is potentially upwelling groundwater from deeper aquifers in contact with carbonaceous shales.

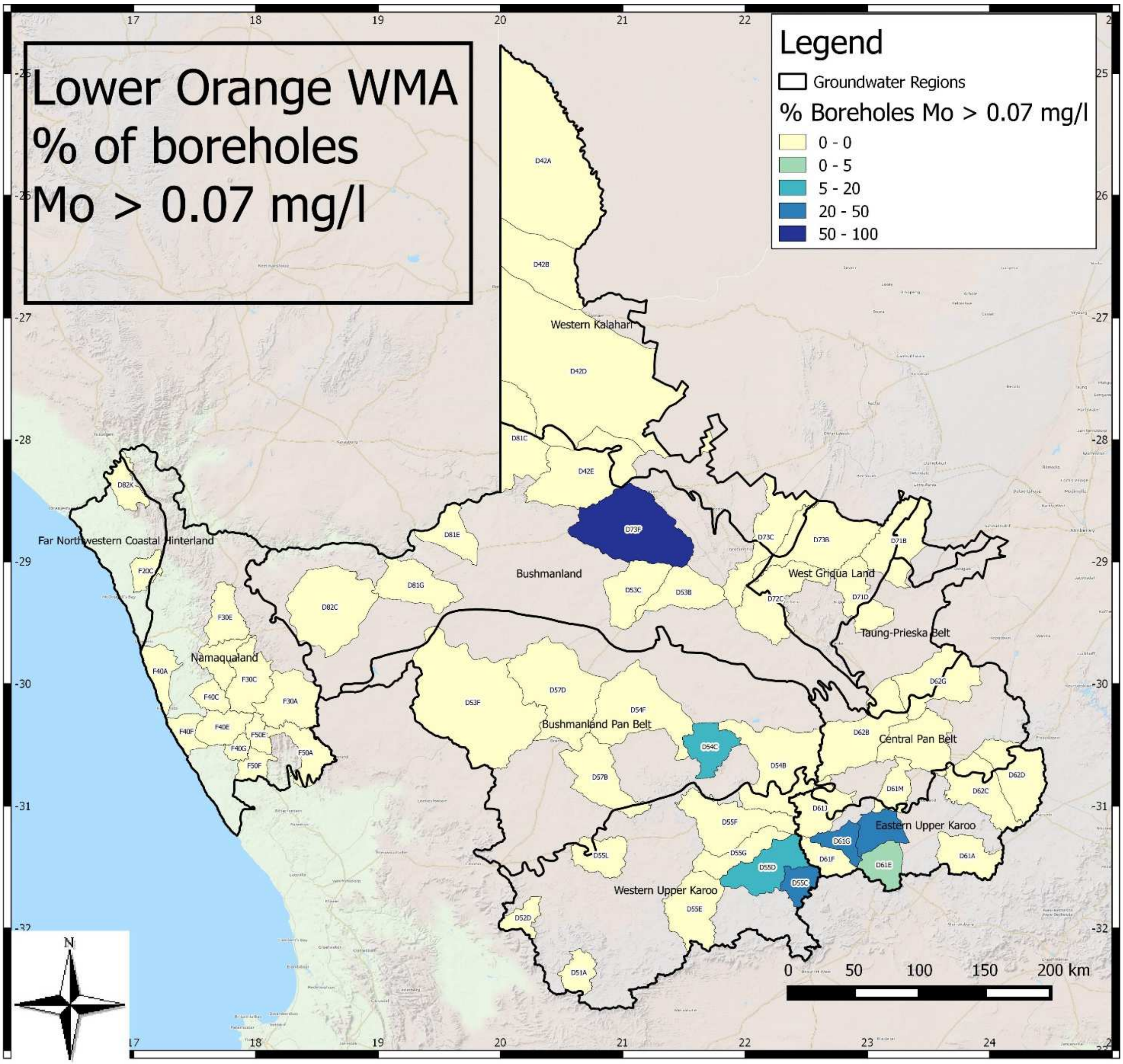


Figure 3.38 Fraction of boreholes with Mo > 0.07 mg/l in the Lower Orange WMA

Cadmium

Cadmium has a low solubility under conditions of neutral or alkaline pH and is highly soluble under acidic conditions, where toxic concentrations can easily arise. Cadmium occurs in association with Zinc ores. It is of concern as it bioaccumulates in the food chain. Its occurrence is restricted to mineralised areas of Bushmanland and Namaqualand (Figure 3.39).

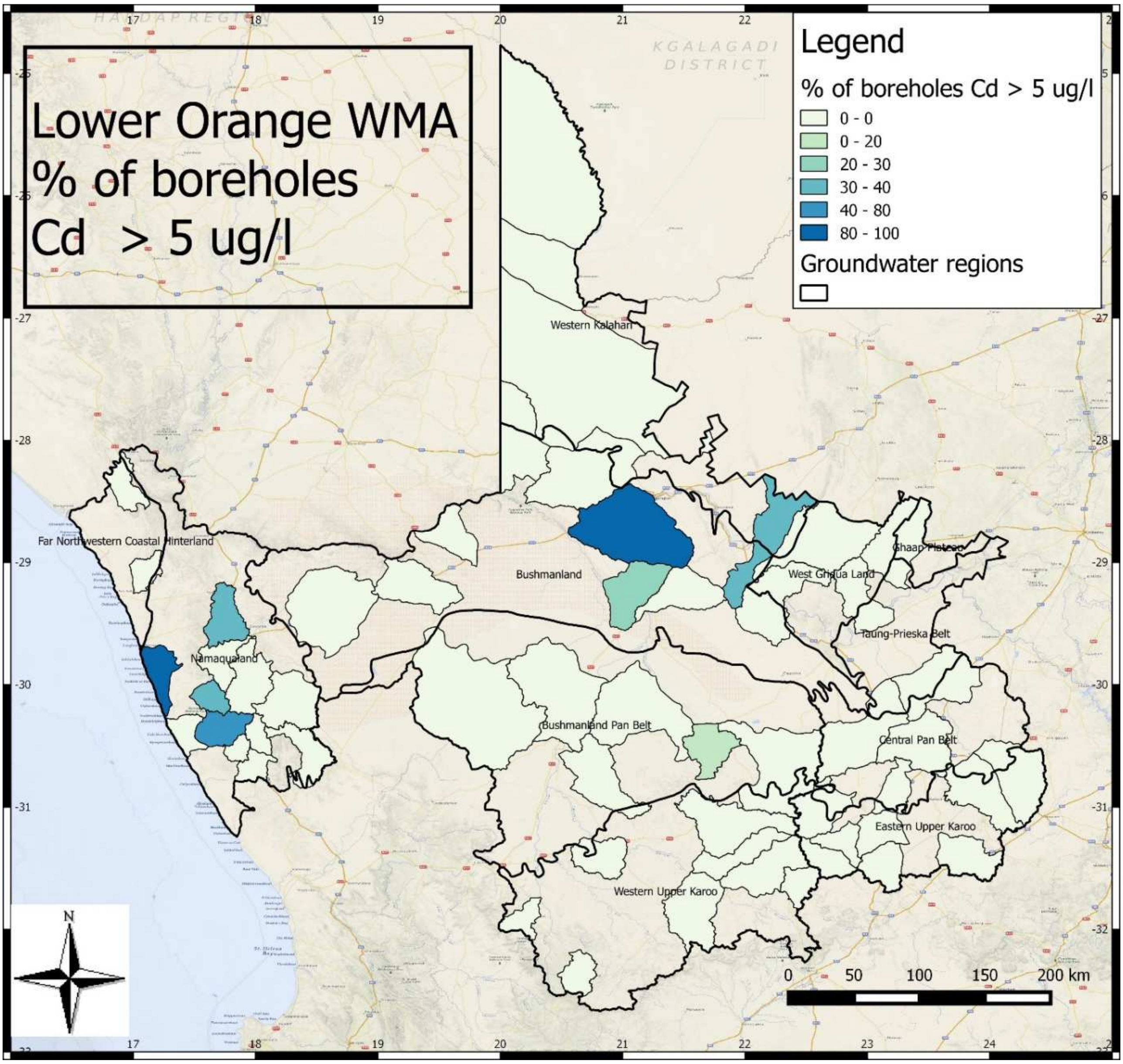


Figure 3.39 Fraction of boreholes with Cd > 5 ug/l in the Lower Orange WMA

3.12 AQUIFER VULNERABILITY

Some aquifers are susceptible to contamination from surface due to shallow groundwater tables, thin soil cover, coarse soils with low clay content and unconfined aquifer conditions. Fractured aquifers allow rapid entry and migration of contaminants via preferred pathways and have the potential to contaminate vast areas along the fracture network.

The DRASTIC Approach to aquifer vulnerability assessment is based on superimposing various layers of data with prescribed ratings. The final outcome/rating is then used to categorise the level of vulnerability. Higher ratings are associated with aquifers that have higher vulnerability and susceptibility to contamination from surface. The term DRASTIC originates from:

D - Depth to groundwater;
R - Recharge rate (net recharge);
A - Aquifer media;
S - Soil media;
T – Topography;

I - Impact on vadose zone; and
C – Conductivity (Hydraulic Conductivity).

Each of these layers is assigned a value based on a rating. These factors are adjusted by a weighting factor and summed to calculate the DRASTIC index. The DRASTIC formula for groundwater in South Africa according to Lynch *et al*. (1994) is as follows:

DRASTIC INDEX = DrDw + RrRw+ ArAw+ SrSw+ TrTw+ IrIw

The weights of each of the above-mentioned terms are:
Depth to groundwater (Dw) = 5
Recharge (Rw) = 4
Aquifer media (Aw) = 3
Soil media (Sw) = 2
Topography (% slope) (Tw) = 1
Impact of vadose zone (Iw) (Iw) = 5

For this study, the conductivity rating was assessed by using the range of borehole yields and a weighting factor of 3. The Ratings used are shown in Table 3.11.

Table 3-11 DRASTIC ratings

Depth to groundwater (mbgl)	Rating	Recharge (mm/a)	Rating	Aquifer	Rating	Soil	Rating
0 - 5	10	0 - 5	1	Dolomite	10	Sand	9
5 - 15	7	5 - 10	3	Intergranular	8	LmS	6 - 7
15 - 30	3	10 - 50	6	Fractured	6	Slm	5
>30	1	50 - 100	8	Fractured and weathered	3	SCL	4
Topography Slope rating (%)	**Rating**	**Impact of vadose zone**	**Rating**	**Borehole Yield (l/s)**	**Rating**		
0-2	10	Gneiss and Namaqualand	3	0 - 0.1	1		
2-6	9	Griqualand west	4	0 - 0.5	3		
6-12	5	Karoo	5	0.1 - 0.5	5		
12-18	3	Granite	6	0.5 - 0.2	7		
		Dolomite	9	2 - 5	10		
		Kalahari	10				

The DRASTC index is shown in Figure 3.40. A DRASTIC index below 60 is considered low vulnerability, and a rating of above 145 is a high vulnerability. Only the Ghaap plateau dolomites near Campbell and Douglas, and the De Aar area can be considered of moderate vulnerability.

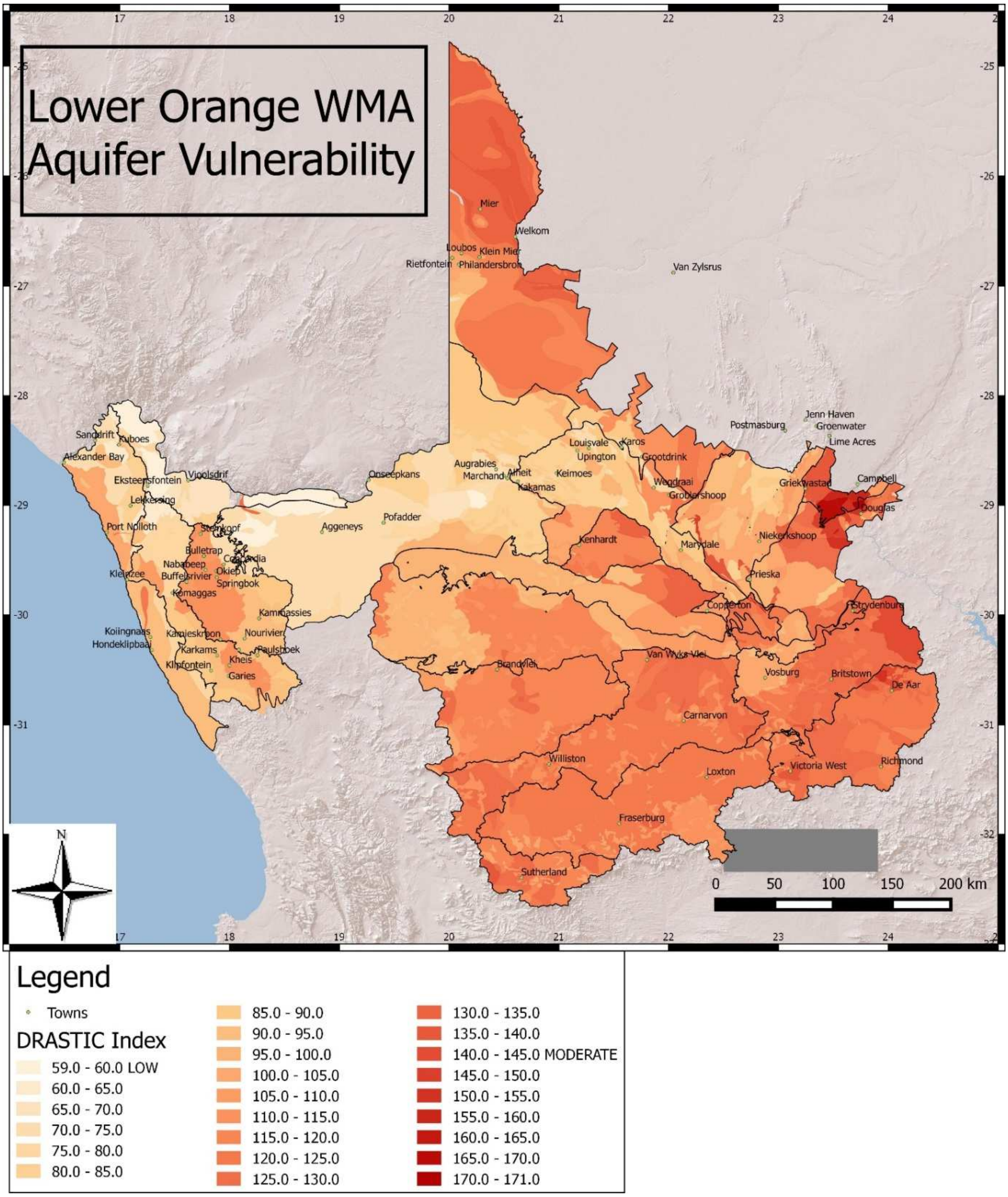


Figure 3.40 DRASTIC index of aquifer vulnerability for the Lower Orange WMA

3.13 SURFACE GROUNDWATER INTERACTION

The interaction of groundwater with surface water depends on the physiography, geology and climate setting of the region. The factors of importance include topography, aquifer type, groundwater levels, rainfall and recharge, and permeability.

Interactions can be expressed as rivers (or pans) gaining baseflow, from groundwater, rivers losing water to groundwater, or riverine vegetation evapotranspirating groundwater in shallow groundwater regions.

Hydrographs indicate where baseflow exists. Hydrographs can consist of three components: direct surface runoff, interflow from temporary perched or high lying springs that respond rapidly to rainfall but are above the regional water level, and groundwater baseflow from the saturated zone. The term baseflow is the delayed flow component from the latter two sources.

3.13.1 Baseflow

For the Lower Orange, GRA II (DWAF, 1996a) lists only two catchments as having baseflow and the baseflow is minimal (Table 3.12). Consequently, groundwater plays a minimal role in maintaining baseflow in rivers.

Table 3-12 Catchments with baseflow

Quaternary catchment	Area (km^2)	MAP (mm/a)	Baseflow (million m^3/a)	Baseflow (mm/a)
D51A	797	312	0.1594	0.2
D73B	3721	258	0.11163	0.04

The hydrology for the Lower Orange as obtained from the Orange-Senqu River Commission (ORASECOM) Phase II study (ORASECOM, 2011) shows the following:

“· In the Vis River in the upper Sak River catchment only 3.5% of the 85 years of record indicated flows in all the months.”

“· In the Renoster River in upper Sak River catchment only 4.7% of the 85 years indicated flows in all the months.”

“· In the Riet River in upper Sak River catchment only 2.4% of the 85 years indicated flows in all the months.”

For the Coastal Rivers on the West coast, the following percentage of years had perennial baseflow: F50A (Groen River) 31.8%, F50B 4.7%, F50C 2.4%, F50D 9.4%, F50E 3.5%, F50F 3.5%, F50G 3.5%, F60A (Sout River) 55.3 %, F60B 55.3%, F60C 55.3% and F60D 55.3%.

It is however important to note that the Coastal Rivers on the West Coast are falling into the rainfall zone where transition from the summer to the winter rainfall area within South Africa is taking place. This results in rainfall, although low, occurring almost throughout the year and thus producing flows throughout the year during the higher rainfall years. The base flows found in these catchments therefore is not necessarily due to groundwater surface water interaction, but rather due to the rainfall occurring throughout the year. No gauging weirs exist to calibrate these volumes, so the flows are uncertain.

The other tributaries of the Lower Orange are mainly zero or close to zero years with perennial flow, except the Orange River main stem that flows most of time for the entire year due to flows from the Upper Orange and Vaal River entering the Lower Orange.

3.13.2 Wetlands

Since groundwater does not drain via baseflow, the only other natural discharges for groundwater are to the sea in the coastal catchments, and via seepage to pans and evaporation.

Many wetlands depend on a contribution from groundwater, which may vary over time depending on water levels and hydraulic gradients. Consequently, abstraction around the wetland may alter its water balance.

Depression wetlands exist in the Bushmanland Pan belt and the Western Kalahari (Figure 3.41). These occur in surface depressions that are endoreic areas, where the groundwater is closer to the surface.

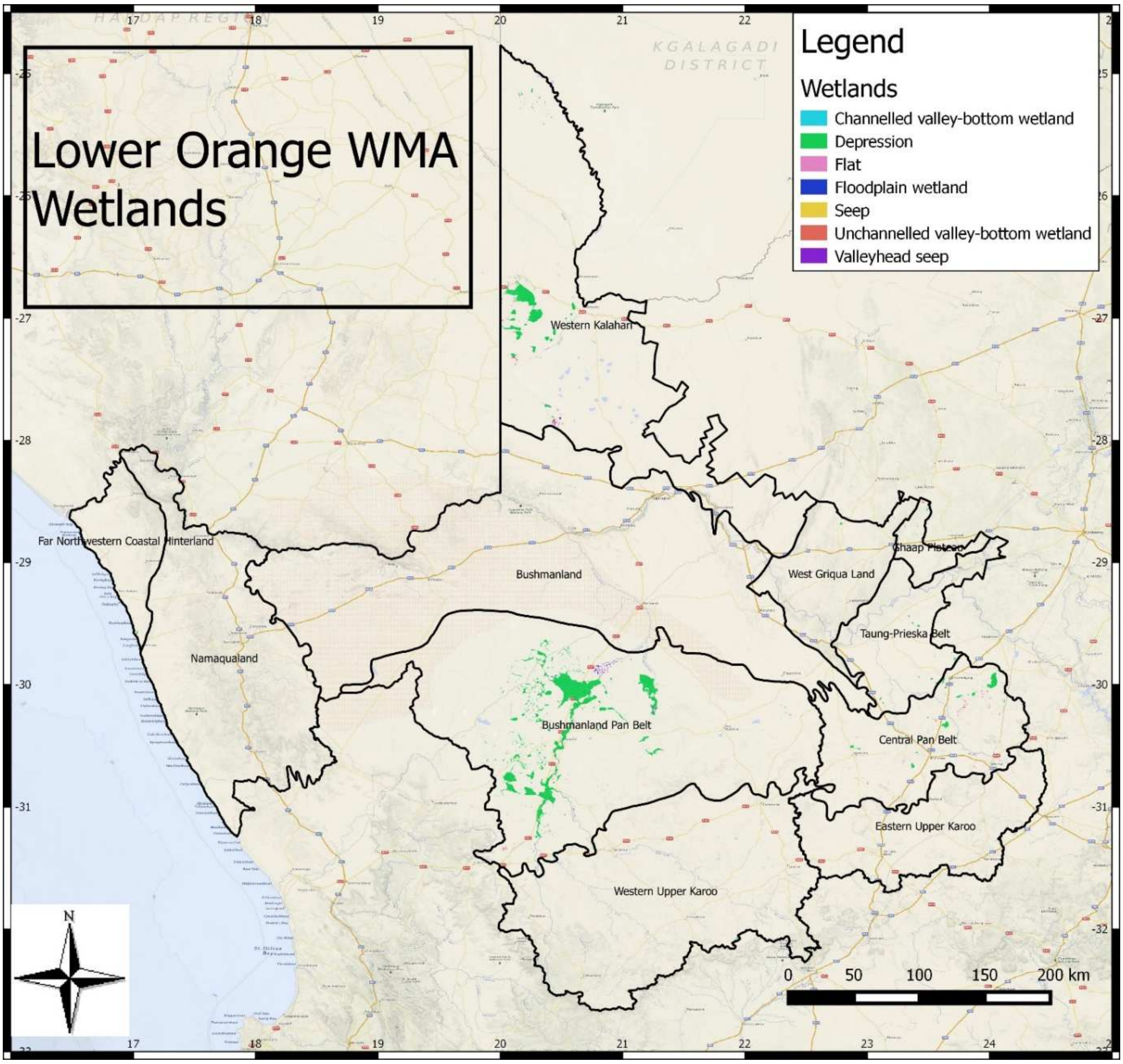


Figure 3.41 Location of wetlands in the Lower Orange WMA

3.14 AQUIFER CLASSIFICATION

According to Wentzel and Parsons (2006), groundwater resources can be classified by the significance of the aquifer:

- **Sole-source aquifer:** An aquifer used to supply >50% or more of water for a given area and for which there are no reasonably available alternative sources of water.
- **Major aquifer:** A high-yield aquifer system of good quality water with a Harvest Potential greater than 50 000 $m^3/km^2/a$ or average borehole yield greater than 2 l/s.
- **Minor aquifer:** A moderate-yield aquifer system of variable water quality with a Harvest Potential between 10 000 and 50 000 $m^3/km^2/a$ or average borehole yield between 1 and 2 l/s.

- **Poor aquifer:** A low- to negligible-yield aquifer system of moderate to poor water quality with a Harvest Potential less than 10 000 m^3/km^2/a or average borehole yield less than 1 l/s.

The aquifer classification of the Lower Orange WMA is shown in Figure 3.42. The bulk of the region is a sole source aquifer of great regional importance, except Bushmanland, the Far Northwestern Coastal Hinterland and northern Namaqualand, which is a poor aquifer.

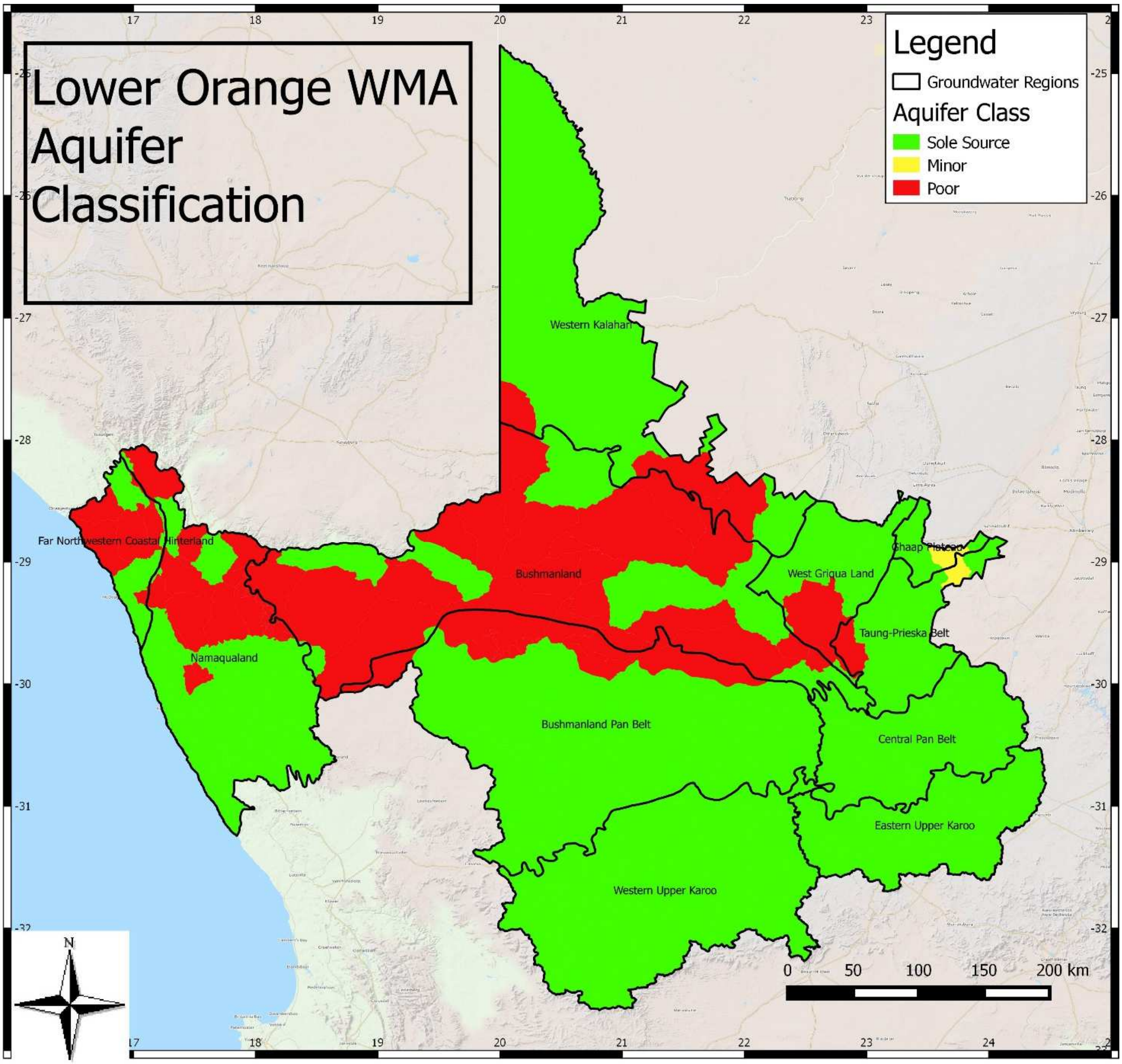


Figure 3.42 Aquifer classification of the Lower Orange WMA

3.15 FRACKING IN THE STUDY AREA

3.15.1 Background

Hydraulic fracturing uses high-pressure solutions to create and prop open fractures in rock to improve the flow of oil, gas, or water. More than 750 different chemicals, ranging from benign to toxic, have been used in hydraulic fracturing solutions. Although these additives are less than 2% by volume of the total fracturing fluid, hydraulic fracturing is a water-intensive process hence the volumes of water and chemicals involved are large (typically 10,000 m3 of water per hydraulic fracturing project).

The contamination from fracking would consist of:

a) The current groundwater and methane that is captured in the organic Ecca shale and is of unacceptable quality for domestic use.
b) The fracking fluids that will be used during the process; and
c) The existing elements in the shale that will be released due to input of fracking fluids (As, Mo, and a host of elements associated with organic sediments).

Contamination from deep hydraulic fracturing requires that there is either a pre-existing hydraulic connection between the shales and shallow groundwater via faults, fractures or dyke contact zones, or that fracking may create such hydraulic connection and allow deep saline groundwater and fracking chemicals to migrate upward into shallow groundwater.

The necessary condition for upward flow from the target formation to upper aquifers is an upward head gradient. In sedimentary basins, upward head gradients are generated by one of two mechanisms: topography or overpressure. Topographic gradients create focused discharge areas (e.g., near a river valley or coast). An example of an aquifer with topographically induced upward gradients is the Table Mountain sandstones. In overpressured zones, upwelling may be more wide spread, but is much slower due to the low vertical permeability of confining low permeability beds. Under either driving mechanism, in order for upward flow to occur, the head gradient must be large enough to overcome density gradients associated with increasing salinity with depth.

Where an upward head gradient exists, and permeabilities are low, vertical fluxes are low. In addition, timescales for transport will be long (1000s of years). Hydraulic fracturing increases the permeability of the target formation, and its immediate boundaries, which is a small thickness compared to the thickness of overlying bedrock. Hydraulic fracturing affects a much smaller thickness of rock than that of the overburden. Similarly, the elevated pressures associated with the fracking process are both short lived and localised to the fracture network, due to bedrock properties that limit pressure propagation at depth.

After fracking, hydrocarbon extraction creates a low-pressure zone that draws fluids toward the target formation, thereby eliminating any potential for upward flow. Consequently, rapid upward migration of brine is not physically plausible while fracking occurs. Upward flow would require that pressures re-establish themselves after fracking, but would occur post-fracking.

Once fracking is complete and the pressures in the aquifer rebuild, one of two possibilities could occur:

- If the carbonaceous shale is not capped by an impermeable geological boundary, the fresh water in the shallow aquifer utilised in the area will be polluted eventually from the deep water. Due to the depths involved and the low vertical permeabilities of the rocks involved, this process is likely to be slow. Or:
- If pressures do not recover because the shales exist as a closed system with impermeable boundaries and there will be no water pollution from depth.

The above assumes that the entire fracked reservoir is successfully plugged to prevent rapid upward migration of contaminants through the fracking wells.

3.15.2 Target Formation

The target Formation in the study area would be the carbonaceous Ecca shales, which occur in the southern half of the study area and dip under the Karoo sandstones. These shales are hydraulically over-pressured (as determined from historic SOEKOR wells), meaning that the natural hydraulic gradient for gas and water is upward.

The gas in the black Ecca shales targeted for fracking formed due to deep burial and rapid gas generation in the geological past subsequent to sediment deposition. For overpressure to persist to present day the permeability of overburden rocks must be sufficiently low to prevent pressure loss from diffusing across them. Consequently, upward fluid fluxes will be extremely small. The effective hydraulic isolation of these formations is evident from the fact that marine water and gas remain trapped in these sediments for hundreds of millions of years.

3.15.3 The Karoo aquifer

This region has an arid climate, with only 200 - 400 mm average rainfall, and ground water forms the sole source of water supply to many communities, small towns, farms and other users.

The carbonaceous shale targeted forms the lowest rock formation of the Karoo Basin (except the underlying Dwyka tillite) consisting of 10 - 150 m thick organic-rich shale, known as the Whitehill Formation. Where it lies between 1500 - 6000m below surface, it is considered prospective for unconventional Shale Gas. This means that the southern margin of the study area underlain by Karoo sandstones, mudstones and shales, and where the carbonaceous Ecca shales are deeply buried, form the most likely target area.

A cross section across the Karoo is shown in Figure 3.43.

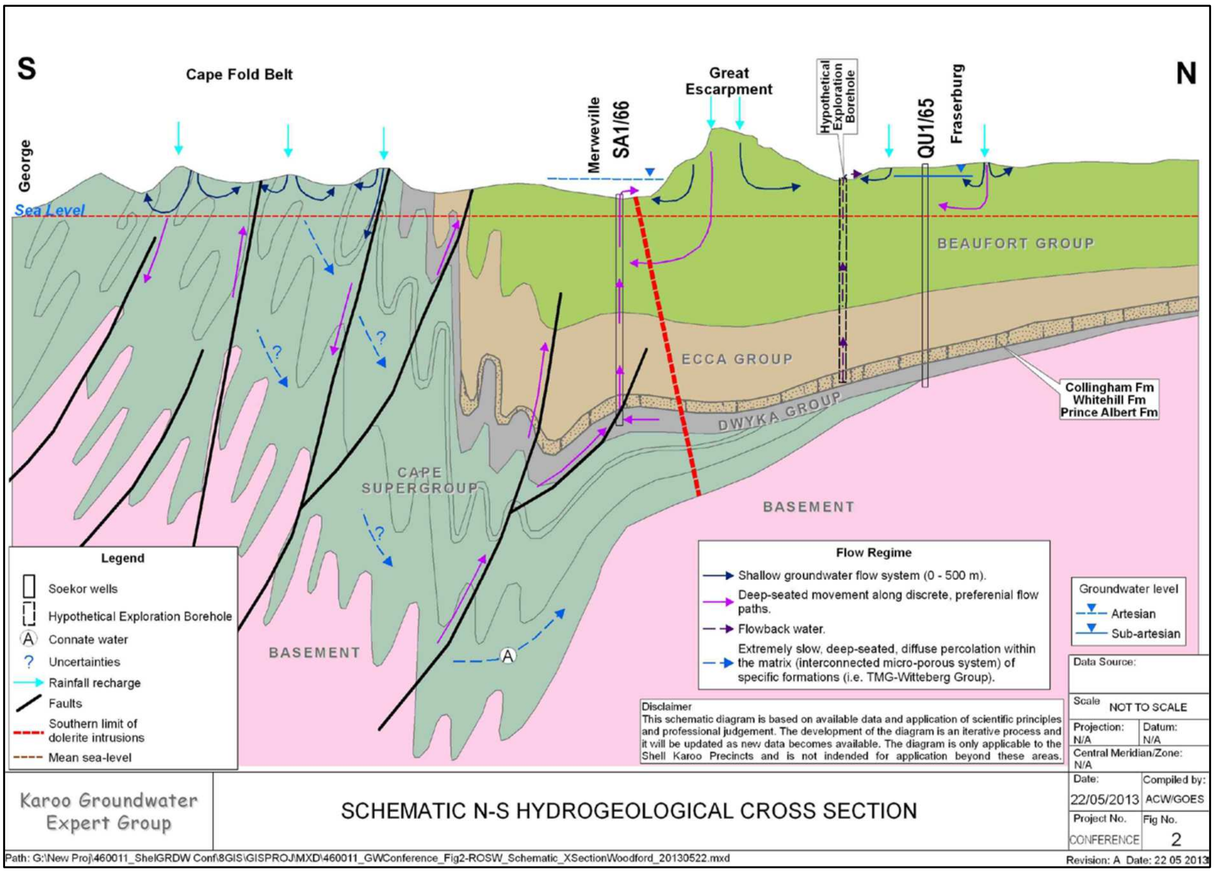


Figure 3.43 Cross section across the Karoo (source: Rosewarne et al., 2013).

Karoo rocks generally have low primary porosities and permeabilities, with exploitable ground water storage and flow occurring in openings such as fractures, faults, margins of intrusive dyke bodies, and bedding planes. Although borehole yields are generally less than 5 l/s, high- and anomalously high-yielding boreholes are located on structures and dolerite contact zones and provide most of the region's water supply.

Thick dykes and their contact zones extend for up to tens, even hundreds of kilometres on surface but their vertical continuation is uncertain. It remains to be proven to what depths single dykes and their contact zones continue uninterrupted. The thickest sills are associated with the Ecca Group, while nested, saucer-shaped ring structures occur in the Beaufort Group. These dykes and sills likely form compartments and increasing the complexity of the system.

North of the Great Escarpment, where the WMA is situated, Karoo rocks are extensively intruded by dolerite sills, dykes and ring-structures. The Karoo geology and hydrogeology associated with the dolerite intrusions, and fault/fracture zones, is poorly understood, and is virtually unknown at depths below 150 m, except from rock-cores from a number of deep holes drilled by SOEKOR in the 1960s and 1970s (up to 4 km deep). The high temperatures of these igneous intrusions (ca.1100 degrees centigrade) are known to have had a considerable impact on gas-escape from the shales in the geological past, and may have reduced its gas potential.

To the north of the escarpment, groundwater systems may be more 'stagnant' and hence more saline, because 'flushing' of the deep aquifer is not taking place due to the low recharge and the synclinal structure of the basin. Due to the relatively shallow shale gas depth, it is also unlikely that the piezometric head in any deep groundwater encountered would be sufficient to cause natural outflow at the wellhead.

Groundwater is unlikely to occur in a continuous aquiferous zone from the <150 m shallow aquifer zone to the deep formations where thermal (defined as >25°C), brackish to saline, very old water occurs under pressure. The shallow aquifer may be separated from this deeper groundwater by zones of effectively impermeable rocks, possibly hundreds to thousands of metres thick, varying from area to area

Ground water quality is generally potable in the shallow aquifer, with Total Dissolved Solids (TDS) concentrations in the range 0.5 – 1 gram per litre (seawater has 35 grams per litre). The TDS fluctuates, however, due to the generally low but episodic recharge occurring in the arid climate, and is brackish in some areas, suspected to be due to upward flow of deeper saline ground water. The presence of elements associated with organic materials not found in continental sandstones and mudstones (Section 3.11) gives further credence to the potential of upwelling water occurring in some localities in the Karoo. This suggests that borehole casing failure may not be necessary to result in upwelling of fracking fluids and deep saline groundwater into the shallow good quality aquifer. The time scale and potentially localities of upwelling groundwater is currently unknown.

4 GRU DESRCIPTION AND PRIORITISATION

4.1 DELINIATION OF GRUs

The process of delineation of GRUs was described in the RU report (RDM/WMA06/ 00/CON/COMP/0116). The final GRU delineation is shown in Figure 4.1.

4.2 CRITERIA FOR PRIORITISATION OF GRUs

In order to prioritise and select the most important GRUs, the criteria assessed per RU include:

- Importance of the RU to users (degree of groundwater dependence).
- Threat posed to water resource quality for users (aquifer vulnerability).
- Threat posed to water resource quality for the environment (baseflow).
- Degree of use (stress index).

4.3 DESCRIPTION OF GRUs

A brief summary of the GRUs is given in this Chapter and Table 4.1. GRUs are described in terms:

- Water quality Class distribution
- Groundwater use and Stress Index
- Present Status Category relative to the stress index
- Groundwater Dependency
- Groundwater EWR and the Basic Human Need Reserve which includes Schedule 1 users
- Allocable Groundwater
- The stability of water levels (Yes) or observable downtrends in groundwater levels (N)
- Water level drop since the beginning of water level records

Table 4-1 Catchments in each GRU and defining characteristics

GRU No.	GRU	Main Characteristic	Quaternary catchment
1	Bushmanland east	Metamorphic Terrane	D53C D62H D72A, D72B, D72C D73C, D73D, D73E, D73F
2	Bushmanland west	Metamorphic terrane of poor groundwater quality Poor water quality	D42E D53A, D53B, D53D, D53E, D53G, D53H, D53J D54D, D54G D81A, D81B, D81C, D81D, D81E, D81F, D81G, D82A, D82B, D82C, D82D
3a	Ecca Carbonaceous shales west	Poor groundwater quality from marine sediments	D53F, D53G D54D, D54F, D57D, D57E
3b	Ecca Carbonaceous shales east	Higher Recharge than western region with better water quality	D62B, D62H, D62G
4a	Dwyka tillite	Poor yield and groundwater quality	D53D, D53F, D53G, D54D, D54G D57E
4b		Poor yield and groundwater quality Higher Recharge than western region	D62H, D62G, D62J
5	Ecca sandstone and shale west	Better water quality than other Ecca shales Pans	D53F D54E D55M

GRU No.	GRU	Main Characteristic	Quaternary catchment
			D55M D57A, D57B, D57C D58B, D58C
6	Ecca sandstone and shale south and central	Lack of pans	D52D, D52E, D52F D54A, D54B, D54C, D55F, D55J, D55L, D58A,
7	Ecca sandstone and shale east	Higher recharge than the western region	D61C, D61H, D61J, D61K, D61L, D61M D62A, D62B, D62C, D62D, D62E, D62F, D62G
8	Far Northwestern Coastal Hinterland	Coastal metamorphic Terrane	D82K, D82L F10A, F10B, F10C F20B, F20C, F20D, F20E
9	Ghaap Plateau	Dolomitic area	C92B, C92C D71A, D71B
10	Karoo sandstone and shale west	Potential for fracking	D51B, D51C D52C D55A, D55B, D55C, D55D, D55E, D55G, D55K D56D, D56F, D56G, D56H, D56J
11	Karoo sandstone and shale east	Potential for fracking Higher recharge than the western region and moderately yielding	D61A, D61B, D61C, D61D,D61E, D61F, D61G D61H, D61L D62C, D62D
12	Namaqualand east	Metamorphic Terrane	D82D, F30A, F30B, F30C, F30D, F30E,
13	Namaqualand west	Metamorphic Terrane Poor water quality	F20A, F20B F30F, F30G F40B, F40C, F40E, F50A, F50B, F50C, F50E, F50F,
14	Taung-Prieska belt	Tertiary cover over underlying geology	C51M C92B, C92C D33K D62G, D62J D71A, D71B, D71C, D71D D72A, D72B
15	West Griqualand	Ironstones	D71B, D71C, D71D D72A, D72B, D72C D73A
		Baseflow	D73B
16	Western Kalahari	Kalahari cover and fractured aquifers	D42A, D42B, D42C, D42D D73C, D73D, D73E
17	Richtersveld	Metamorphic Terrane	D82A, D82D, D82E, D82F, D82G, D82H, D82J
18	Namaqualand coastal	Sediment cover over Nama and Vanrhynsdorp Group	F40A, F40D, F40F F50G F60A
19	Karoo sandstone and shale southwest	Higher rainfall	D52A, D52B D56A, D56B, D56C, D56E
		Baseflow	D51A

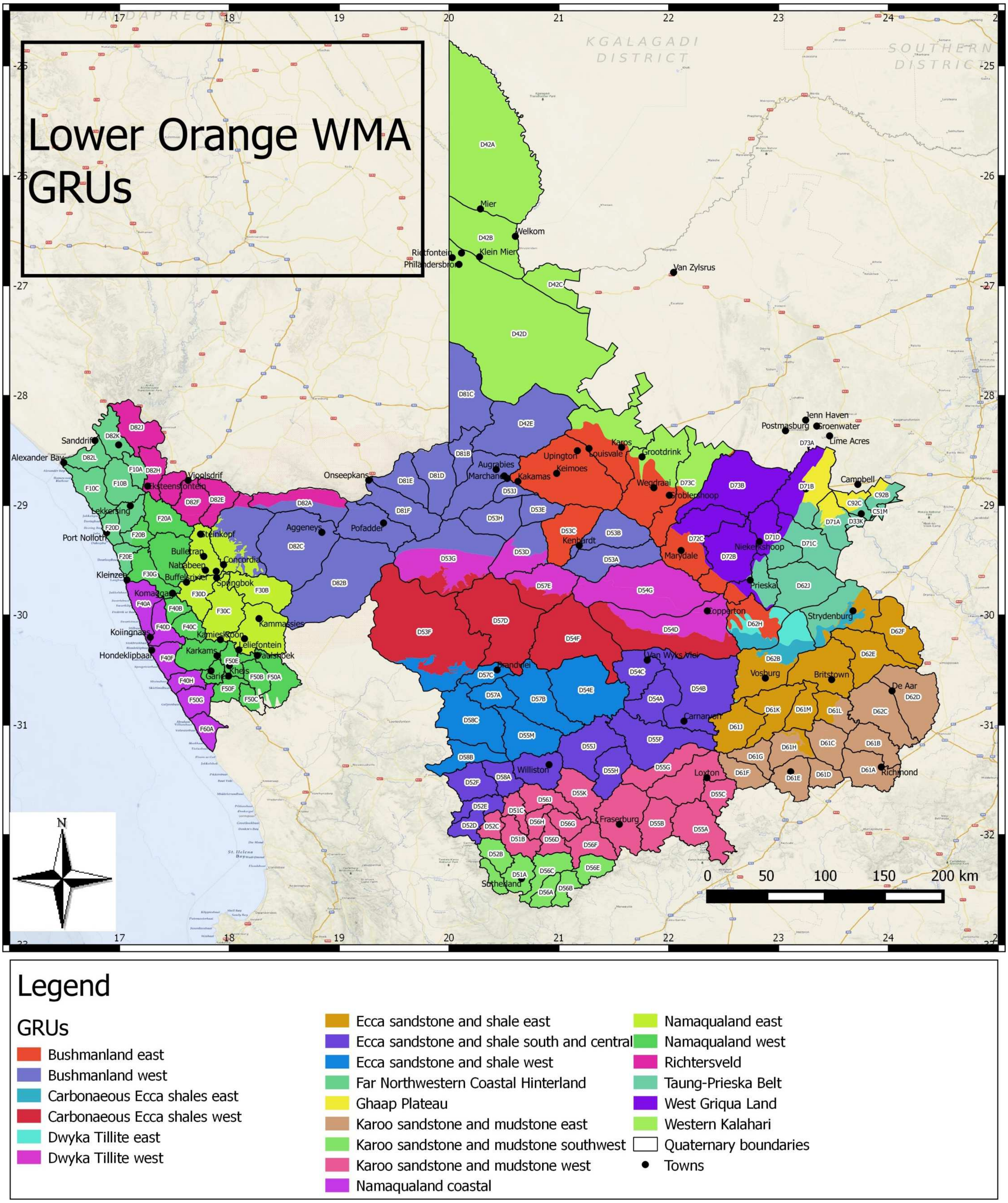


Figure 4.1 Lower Orange GRU delineation

4.3.1 Bushmanland East

The GRU consists of dry rangeland, except along the banks of the Orange, which flows through D73D (Figures 4.2 and 4.3).

Rocks of the Kaaien and Areachap Terranes of the Namaqua-Natal metamorphic Province underlie the GRU. Tertiary cover is less extensive than to the west. Recharge is from less than 1 mm to over 3 mm/a increasing southeastward with rainfall. The aquifer is fractured in nature with yields of 0.5 - 2 l/s. Groundwater levels average 20 - 25 mbgl.

70 - 95% of boreholes are potable (Table 4.4). Groundwater quality is less saline than in the western area and is generally of Class 2. Nitrates, Fluoride, Molybdenum and Arsenic are frequently a problem.

Groundwater dependency is low to moderate and the towns of Marydale and Kenhardt rely on groundwater. Groundwater use is high in D53C, with most of the groundwater use being for regional water supply schemes for the town of Kenhardt (Table 4.2). The stress index is below 0.2 in the other Quaternaries. Groundwater use is also low in D72C, where groundwater is used to supply Marydale. Groundwater levels have dropped 6 m in D53C but appear to remain stable (Figure 4.4). Groundwater levels have dropped 1 m in D72C (Figure 4.5).

Based on the high level of groundwater dependence, and a high stress index, D53C is considered a high priority catchment in this GRU (Table 4.3).

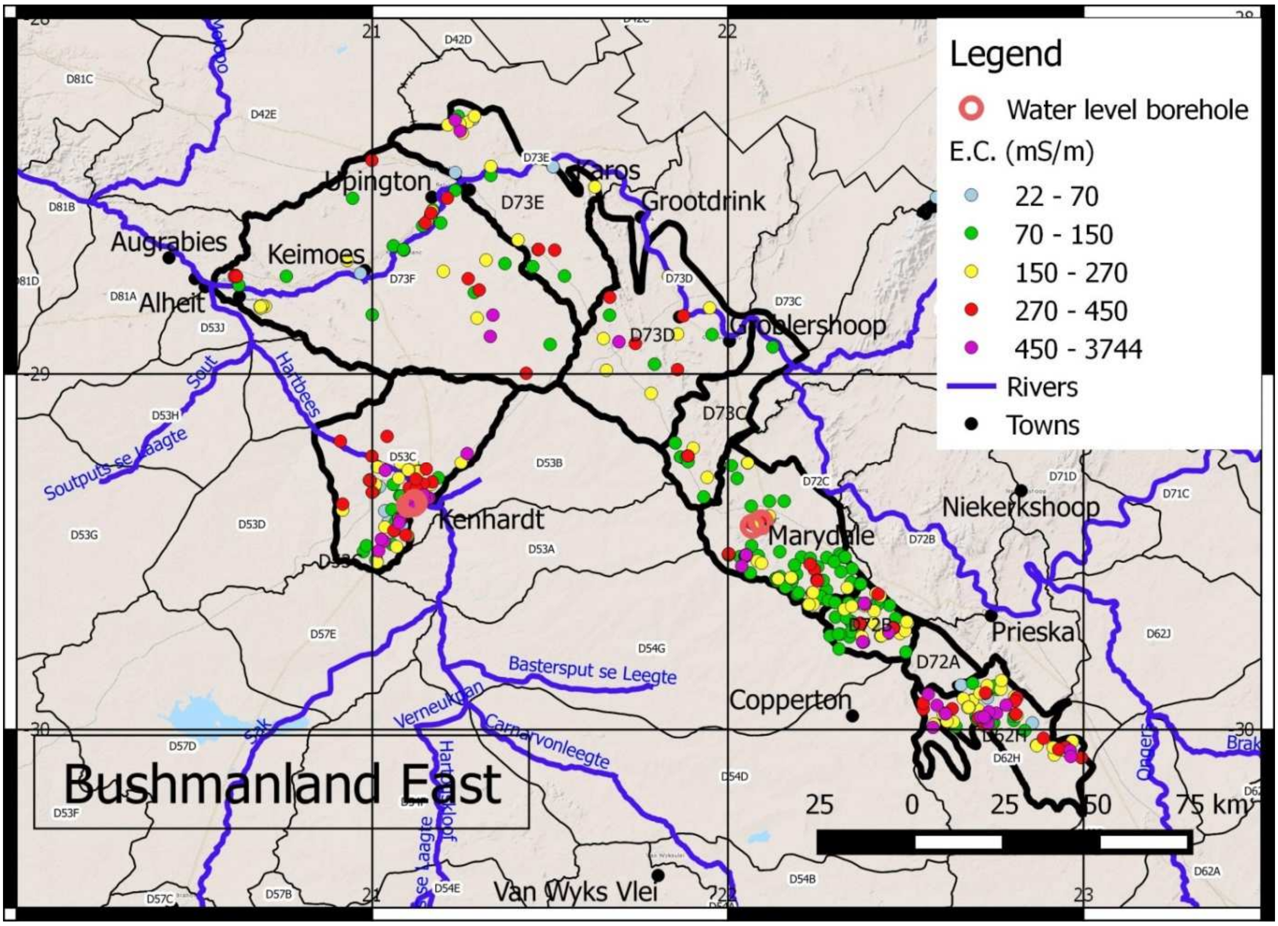


Figure 4.2 Catchments in Bushmanland East GRU and existing monitoring boreholes

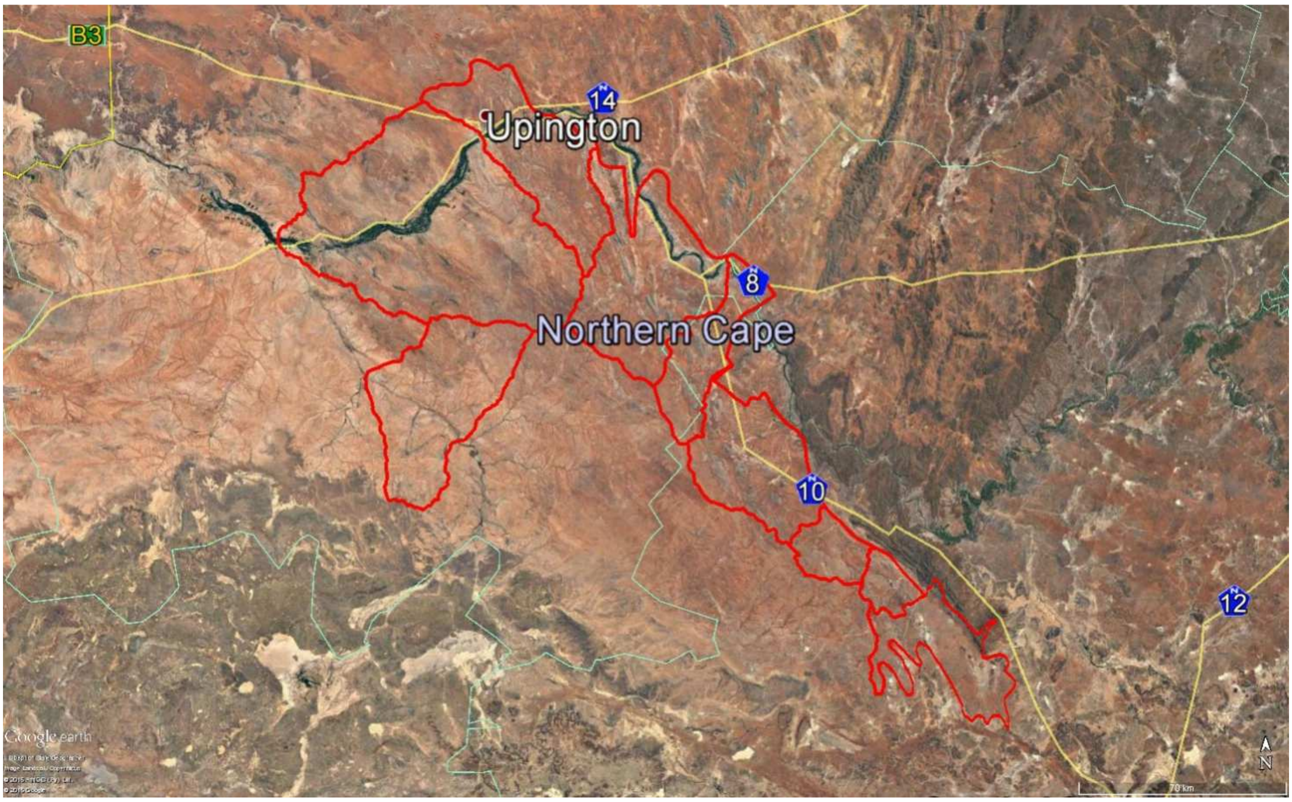


Figure 4.3 Bushmanland East land cover

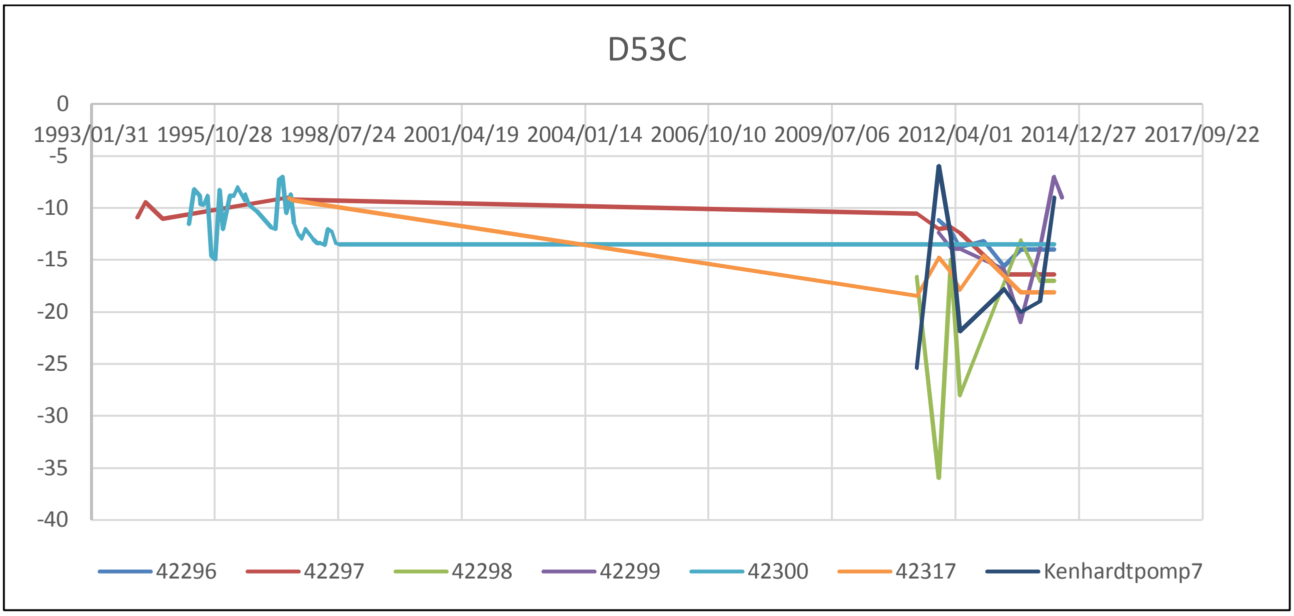


Figure 4.4 Water levels in D53C in mbgl

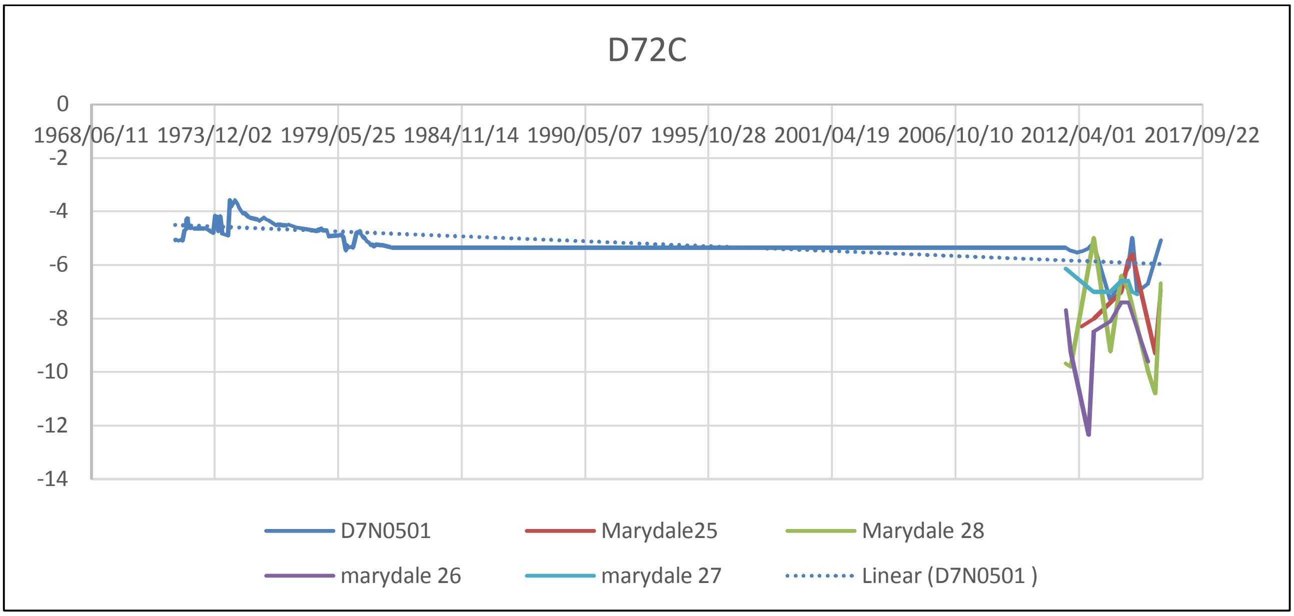


Figure 4.5 Water levels in D72C in mbgl

Table 4-2 Bushmanland East: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D53C	149	100	1899	0.32	0.008	0.071	0.000	0.000	0.015	0.248	0.342	0.263	1.08	F
D62H	216	50	1037	4.37	0.145	0.054	0.000	0.000	0.009	0.000	0.208	0.009	0.05	A
D72A	210	19.5	273	0.95		0.004	0.000	0.000	0.003	0.000	0.008	0.003	0.01	A
D72B	215	16	416	1.26		0.006		0.000	0.007	0.000	0.013	0.007	0.01	A
D72C	200	50	1393	2.63	0.179	0.016	0.000	0.000	0.021	0.245	0.461	0.266	0.17	B
D73C	230	36	881	2.89	0.000	0.080	0.000	0.000	0.031	0.123	0.234	0.154	0.08	B
D73D	185	56	2116	1.39	0.000	0.026	0.000	0.000	0.029	0.000	0.055	0.029	0.04	A
D73E	183	48	1634	1.02		0.030	0.000	0.015	0.019	0.018	0.082	0.037	0.08	B
D73F	158	100	4630	0.97	0.000	0.077	0.000	0.000	0.091	0.000	0.168	0.091	0.17	B
Total			**14279**	**15.80**	**0.332**	**0.365**	**0.000**	**0.015**	**0.225**	**0.634**	**1.571**	**0.859**		

Table 4-3 Bushmanland East: Groundwater Reserve and allocable groundwater

Quat	GW[1] dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D53C	77.49	0	0.018	0.018	**-0.018***	Y	6	High
D62H	70.15	0	0.011	0.011	2.703			Low
D72A	10.32	0	0.004	0.004	0.611	N		Low
D72B	4.46	0	0.009	0.009	0.809			Low
D72C	89.10	0	0.027	0.027	1.409	Y	1	Low
D73C	82.72	0	0.040	0.040	1.721	Y		Low
D73D	82.72	0	0.038	0.038	0.861			Low
D73E	2.26	0	0.025	0.025	0.609			Low
D73F	1.30	0	0.116	0.116	0.503			Low

1 Groundwater

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Table 4-4 Bushmanland East: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D53C	11	43	34	23	16	9	34	27	18	13	69
D62H	5	33	36	18	13	5	31	34	17	12	70
D72A	2	60	46	26	8	1	42	32	18	6	76
D72B	7	91	33	12	11	5	59	21	8	7	85
D72C	5	66	33	8	4	4	57	28	7	3	90
D73C	24	9	9	1	1	55	20	20	2	2	95
D73D	4	6	10	6	3	14	21	34	21	10	69
D73E	4	26	33	17	11	4	29	36	19	12	69
D73F	1	19	12	10	2	2	43	27	23	5	73

4.3.2 Bushmanland West

The GRU consists of dry rangeland, except along the banks of the Orange, which flows through the GRU either through or on the margin of the D81 catchments (Figures 4.6 and 4.7).

The Bushmanland west GRU is underlain by rocks of the Namaqua-Natal Metamorphic Province, which are largely covered by Tertiary cover. Extensive outcrop exists only in the central region from Augrabies to Kenhardt. The aquifer is of the fractured and weathered type and low yielding (0.1 - 0.5 l/s). Recharge is less than 1 mm/a. Mean groundwater depth increases from less than 20 m near Kenhardt to over 50 m to the west near Aggeneys.

Water quality is generally poor and of Class 3 or 4 due to high salinity, with the worst quality water being located in the north from Concordia to Augrabies. Nitrates, Fluoride and Arsenic are frequently a problem. The potability of groundwater is highly variable and ranges from 8 - 80% but is generally low and less than 50% (Table 4.7).

The aquifer is considered poor and no communities rely on it for water supply. Groundwater dependency is low to moderate. Groundwater use is primarily for livestock watering, small-scale local water supply schemed and Schedule 1 water use (Table 4.5). The stress index is high due to livestock water use and many catchments are heavily utilised due to the very low recharge rates. Groundwater levels have dropped 3 m in D81C, which has a stress index of 0.74, but appear to remain stable (Figure 4.10). Groundwater levels appear to remain stable in D42E and D81B (Figure 4.8 to 3.9), however, some boreholes show a significant decline in water levels in D42E.

Catchments with a high stress index (>0.65) were considered of intermediate priority since groundwater dependency in the GRU is limited by the poor water quality. Only B81F, in the Pofadder vicinity, has a high stress index and a groundwater dependency exceeding 50% (Table 4.6).

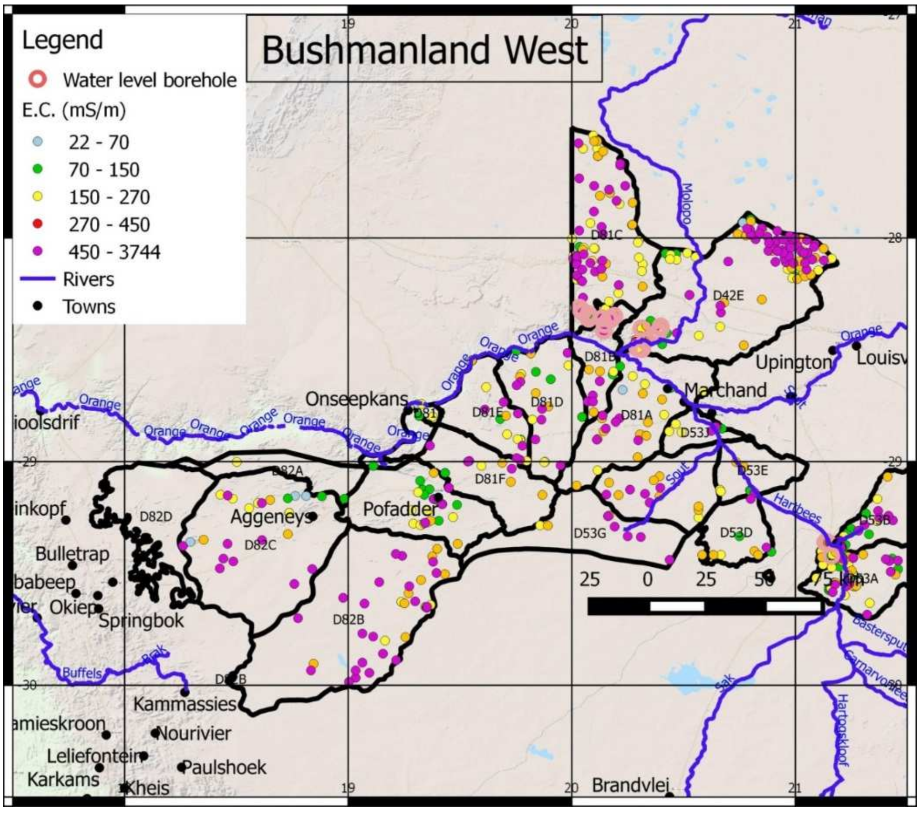


Figure 4.6 Catchments in Bushmanland West GRU and existing monitoring boreholes

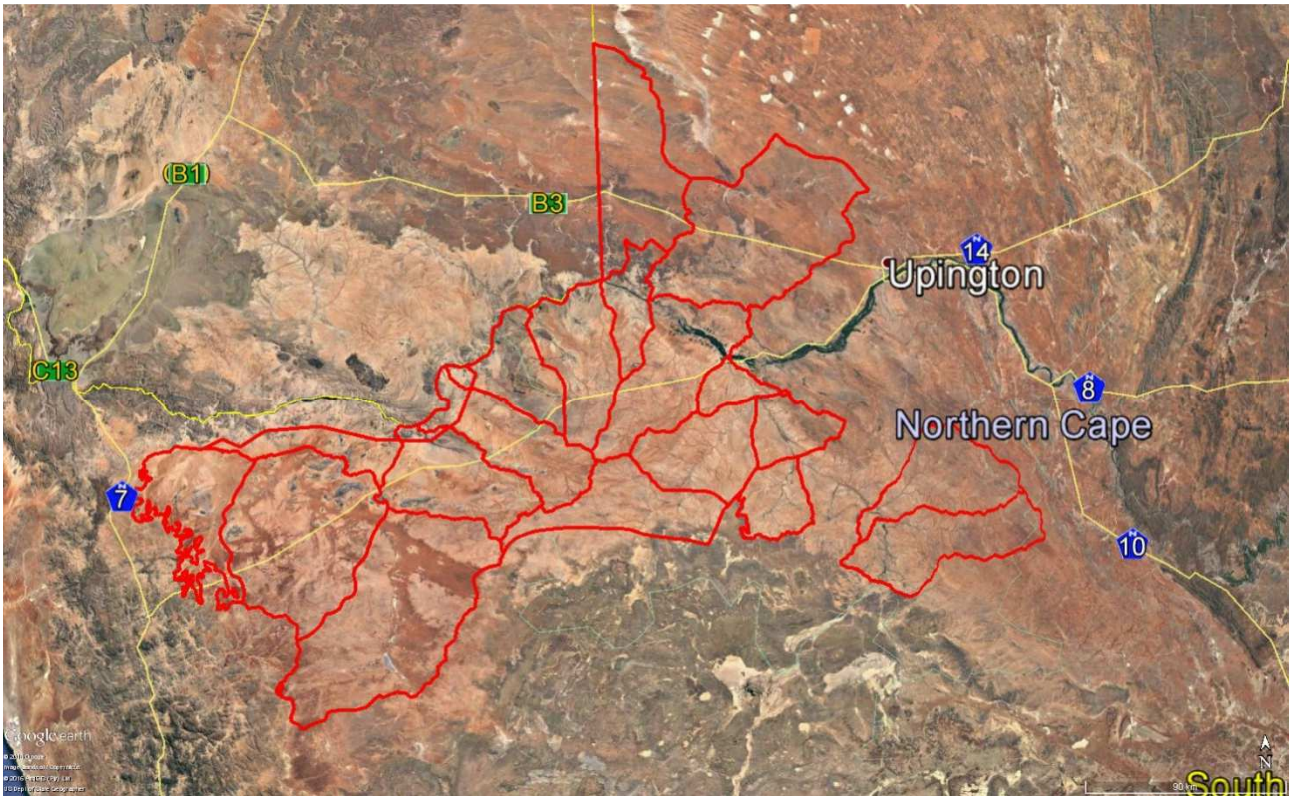


Figure 4.7 Bushmanland West land cover

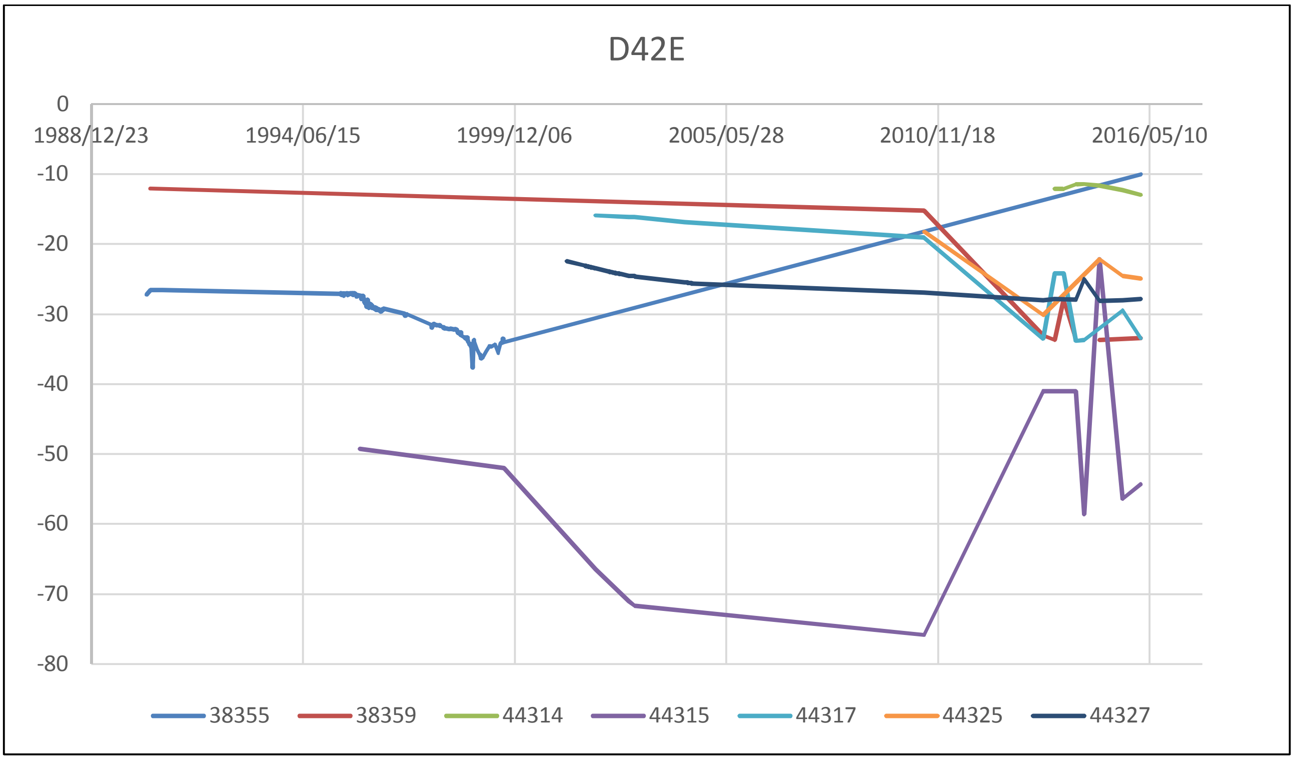


Figure 4.8 Water levels in D42E in mbgl

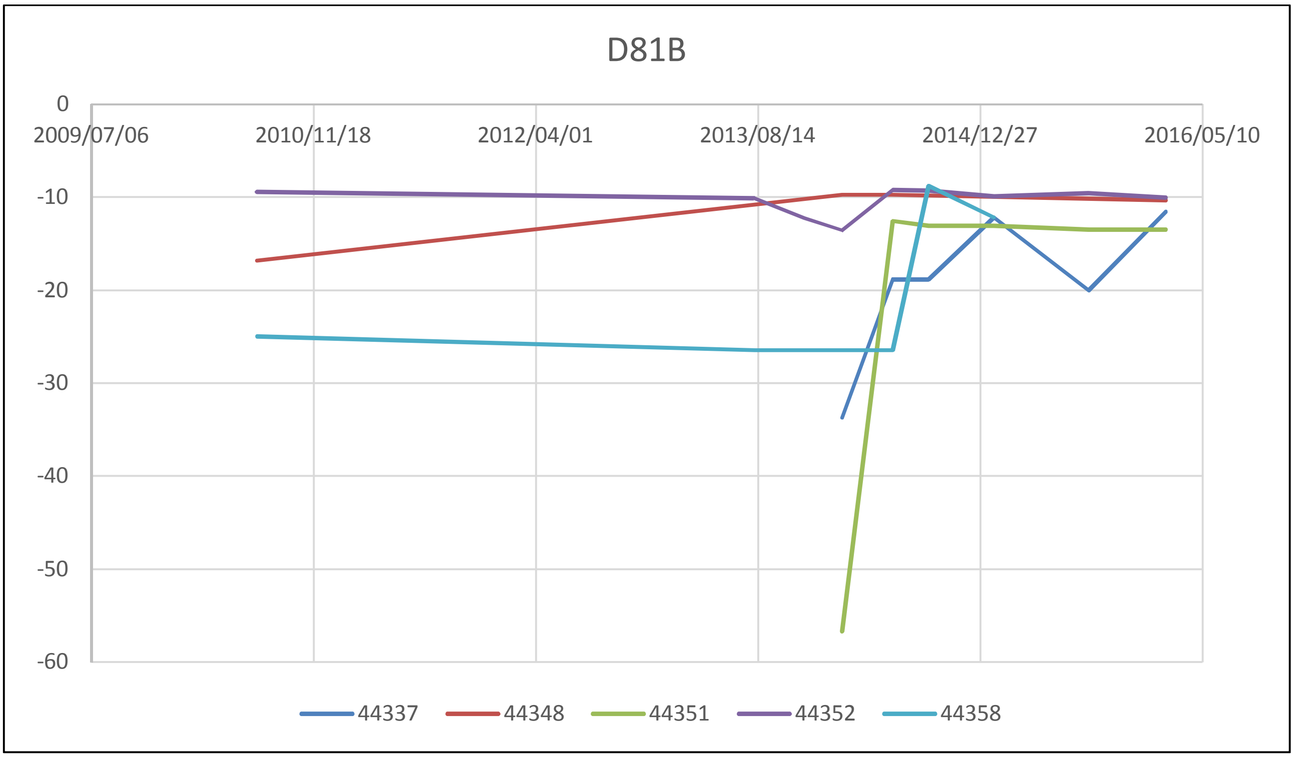


Figure 4.9 Water levels in D81B in mbgl

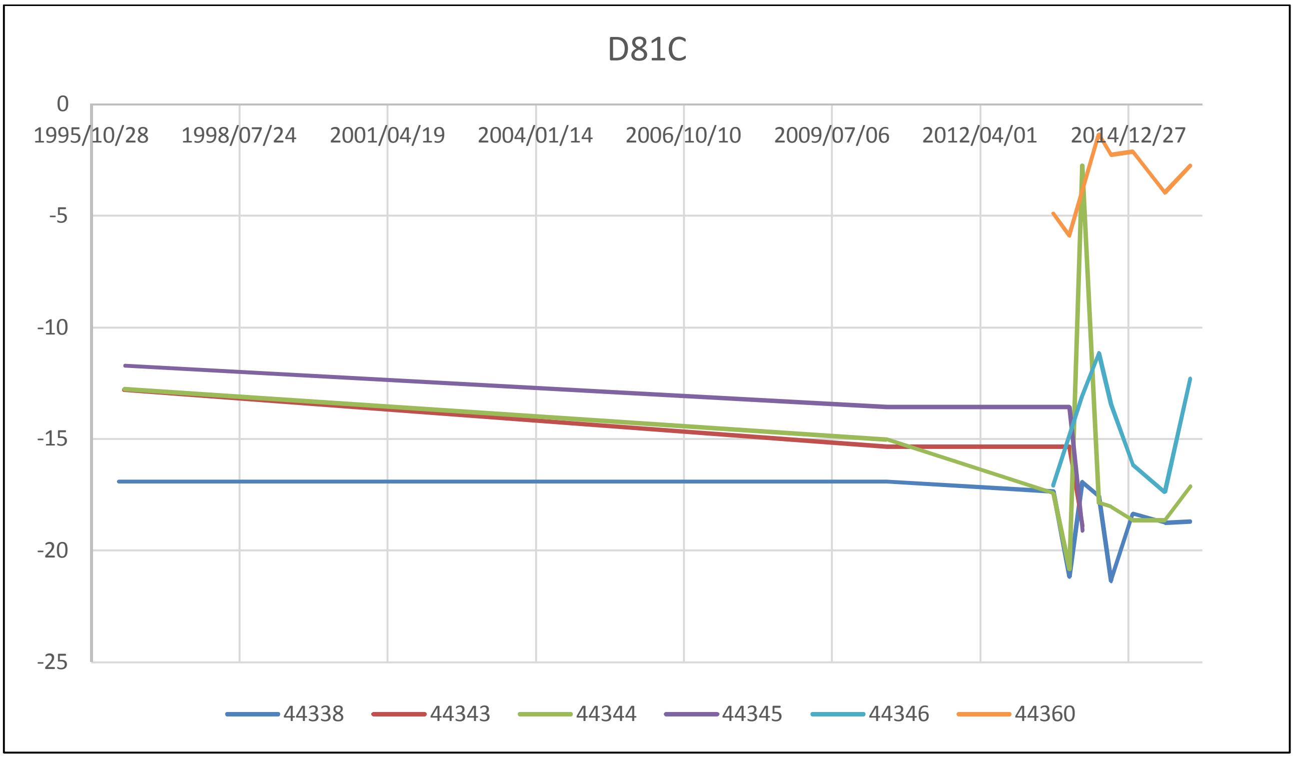


Figure 4.10 Water levels in D81C in mbgl

Table 4-5 Bushmanland West: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D42E	148	100	4208	0.69	0.000	0.157	0.000	0.000	0.061	0.000	0.218	0.061	0.32	C
D53A	160	100	1939	0.42	0.000	0.070	0.000	0.000	0.014	0.006	0.089	0.020	0.21	C
D53B	167	100	1713	0.44	0.000	0.065	0.000	0.000	0.013	0.028	0.106	0.041	0.24	C
D53D	136	45	833	0.10	0.000	0.031	0.000	0.000	0.005	0.021	0.058	0.026	0.59	D
D53E	140	100	826	0.36	0.000	0.031	0.000	0.000	0.005	0.010	0.046	0.015	0.13	B
D53G	99	37	1775	0.26	0.000	0.067	0.000	0.000	0.011	0.000	0.078	0.011	0.30	C
D53H	131	100	1589	0.16	0.000	0.060	0.000	0.000	0.010	0.019	0.089	0.029	0.55	D
D53J	134	100	455	0.05	0.000	0.017	0.000	0.000	0.006	0.000	0.023	0.006	0.46	D
D81A	128	100	2310	0.22	0.000	0.082	0.000	0.000	0.041	0.000	0.122	0.041	0.56	D
D81B	113	100	851	0.05	0.000	0.032	0.000	0.000	0.004	0.015	0.051	0.019	1.02	F
D81C	120	100	2682	0.20	0.000	0.101	0.000	0.000	0.017	0.028	0.146	0.046	0.74	E
D81D	113	100	1823	0.11	0.000	0.068	0.000	0.000	0.012	0.021	0.102	0.033	0.96	F
D81E	97	100	1287	0.04	0.000	0.048	0.000	0.000	0.009	0.000	0.057	0.009	1.35	F
D81F	91	100	1839	0.05	0.000	0.069	0.000	0.000	0.013	0.097	0.179	0.110	3.80	F
D81G	102	100	2005	0.08	0.000	0.071	0.000	0.000	0.010	0.000	0.081	0.010	1.02	F
D82A	77	53	1015	0.01	0.000	0.031	0.000	0.000	0.004	0.042	0.077	0.046	5.63	F
D82B	80	100	4873	0.08	0.000	0.147	0.000	0.000	0.014	0.003	0.165	0.018	2.15	F
D82C	83	100	3991	0.07	0.000	0.125	0.004	0.000	0.018	0.000	0.146	0.018	2.03	F
D82D	111	63	1879	0.10	0.000	0.059	0.000	0.000	0.009	0.000	0.067	0.009	0.66	E
Total			**37891**	**3.49**	**0.000**	**1.329**	**0.004**	**0.000**	**0.277**	**0.289**	**1.900**	**0.567**		

Table 4-6 Bushmanland West: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D42E	27.59	0	0.078	0.078	0.292	Y	0 - 20	Low
D53A	34.14	0	0.018	0.018	0.215			Low
D53B	55.76	0	0.017	0.017	0.216			Low
D53D	28.58	0	0.007	0.007	0.025			Low
D53E	28.34	0	0.007	0.007	0.205			Low
D53G	28.94	0	0.014	0.014	0.116			Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D53H	28.34	0	0.013	0.013	0.046			Low
D53J	6.21	0	0.008	0.008	0.017			Low
D81A	5.77	0	0.052	0.052	0.054			Low
D81B	36.85	0	0.005	0.005	**-0.001***	Y		intermediate
D81C	34.84	0	0.022	0.022	0.030	Y	3	Intermediate
D81D	28.34	0	0.015	0.015	0.001			Intermediate
D81E	9.02	0	0.011	0.011	**-0.011***			Intermediate
D81F	61.06	0	0.017	0.017	**-0.088***			High
D81G	2.50	0	0.013	0.013	**-0.003***			Intermediate
D82A	69.43	0	0.006	0.006	**-0.042***			Intermediate
D82B	40.14	0	0.019	0.019	**-0.060***			Intermediate
D82C	8.51	0	0.023	0.023	**-0.051***			Intermediate
D82D	4.06	0	0.011	0.011	0.021			Intermediate

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Table 4-7 Bushmanland West: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D42E	4	25	24	29	45	3	20	19	23	35	42
D53A	0	16	18	18	18	0	23	26	26	26	49
D53B	1	21	15	10	37	1	25	18	12	44	44
D53D	0	2	1	8	6	0	12	6	47	35	18
D53E	0	2	2	2	1	0	29	29	29	14	57
D53G	0	2	5	6	21	0	6	15	18	62	21
D53H	0	0	1	7	5	0	0	8	54	38	8
D53J	0	2	3	0	2	0	29	43	0	29	71
D81A	1	2	5	10	6	4	8	21	42	25	33
D81B	0	1	2	5	9	0	6	12	29	53	18
D81C	0	4	27	15	36	0	5	33	18	44	38
D81D	0	4	5	4	7	0	20	25	20	35	45
D81E	3	2	8	4	6	13	9	35	17	26	57
D81F	0	3	4	3	5	0	20	27	20	33	47
D81G	1	10	11	3	2	4	37	41	11	7	81
D82A	0	1	1	2	2	0	17	17	33	33	33

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D82B	0	1	5	8	22	0	3	14	22	61	17
D82C	3	2	5	3	10	13	9	22	13	43	43
D82D	1	4	8	7	3	4	17	35	30	13	57

4.3.3 Dwyka Tillite

The GRU consists of dry rangeland. The Sak and the Hartbees River, which are ephemeral cut through the Dwyka Tillite west, and the Ongers cuts through Dwyka Tillite East (Figures 4.11 and 4.12).

The Dwyka Tillite GRU is sub-divided into a western portion and smaller eastern portion. It is underlain by tillites and largely devoid of Tertiary or Quaternary sediment cover. Recharge is less than 1 mm/a, except in the eastern pocket where rainfall is higher. Groundwater levels are from 18 - 25 mbgl, but above 15 mbgl in the eastern portion. Borehole yields are below 0.5 l/s and the aquifer is considered poor.

Groundwater is of unacceptable quality due to salinity of Class 4. Nitrates are frequently a problem, as well as fluorides in the west. The potability of groundwater is poor to unacceptable, except on the NE margins of the GRU, where boreholes are probably drilled through into the Bushmanland rocks. Nearly 80% of boreholes are potable in the Dwyka Tillite East, whereas only 13 - 47% are potable in the Dwyka tillite West (Table 4.10).

Only Copperton obtains water from the aquifer, however, it is a sole source aquifer for the rest of the GRU. Groundwater use is primarily for livestock watering, small-scale local water supply and Schedule 1 water use (Table 4.8). The stress index is low except in D53G, where some mining occurs at LaFarge gypsum. No groundwater level data are available.

All catchments have a stress index of below 0.65, and only D53G has a moderate stress index. Groundwater dependency for water supply is low except with for D54D, D62B and H, all of which have stress indices of less than 0.1. Consequently, the priority of all catchments, except D53G in the GRU is low (Table 4.9).

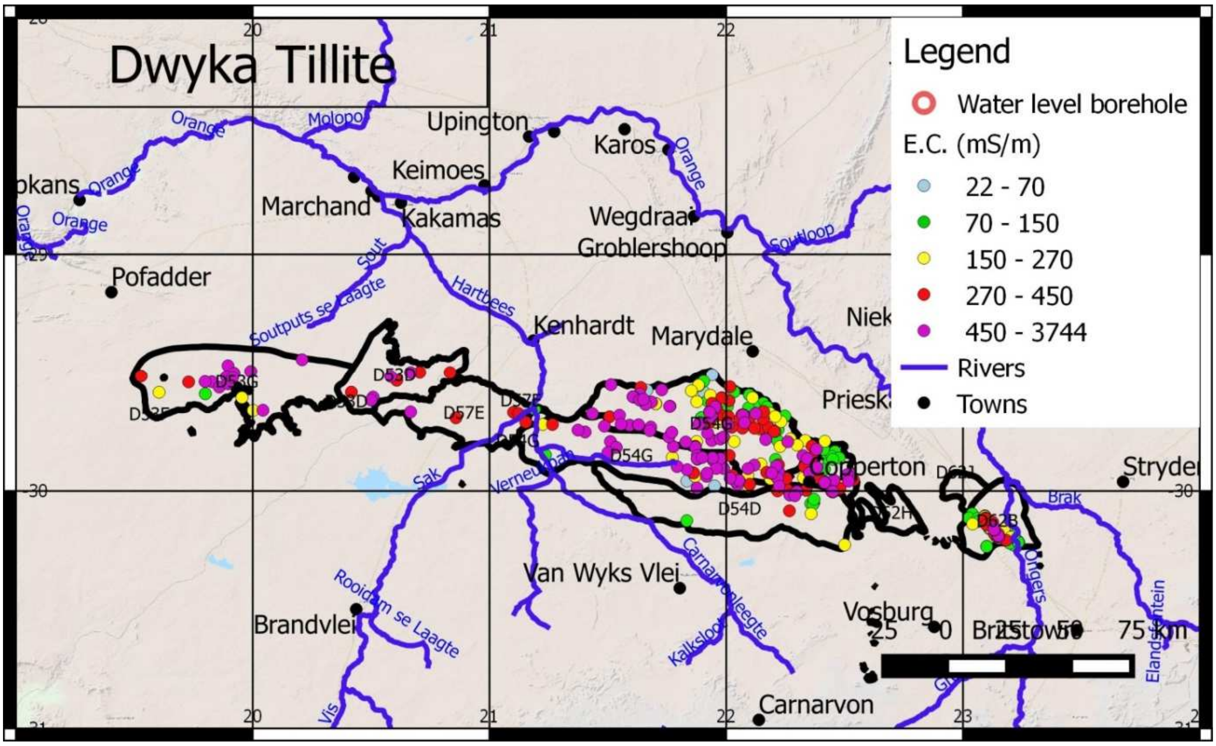


Figure 4.11 Catchments in the Dwyka Tillite GRU and existing monitoring boreholes

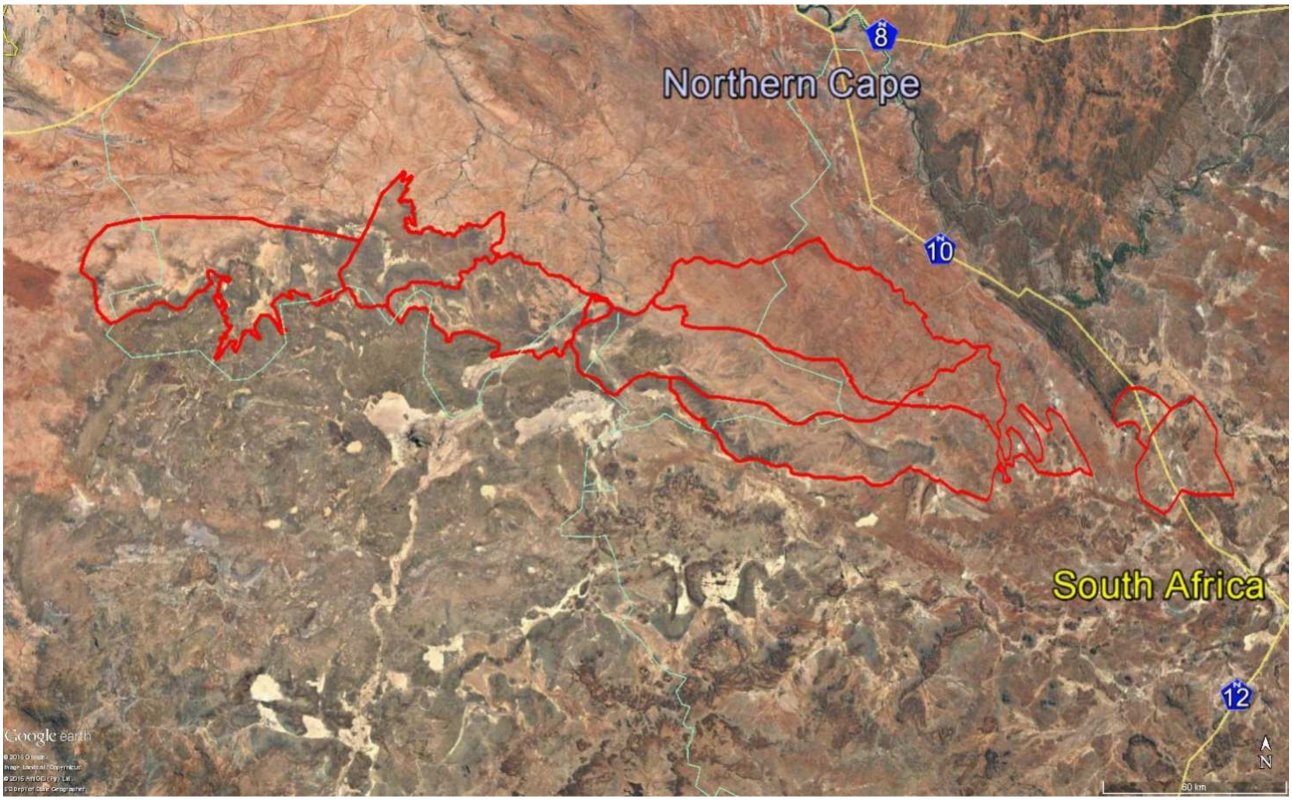


Figure 4.12 Dwyka Tillite land cover

Table 4-8 Dwyka Tillite: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D53D	136	55	1009	0.12		0.038			0.007	0.000	0.045	0.007	0.37	C
D53G	99	47	2244	0.33		0.084	0.065		0.014	0.047	0.210	0.061	0.64	D
D54D	173	47	2371	2.52	0.026	0.130	0.000	0.000	0.018	0.000	0.173	0.018	0.07	B
D54G	169	100	4503	4.28	0.000	0.111	0.000	0.000	0.037	0.004	0.152	0.040	0.04	A
D57E	145	62	1218	0.61		0.046			0.009	0.000	0.055	0.009	0.09	B
D62B	221	20	620	2.63	0.045	0.040			0.008	0.000	0.093	0.008	0.04	A
D62H	216	24	497	2.09		0.026			0.004	0.000	0.030	0.004	0.01	A
Total			**12461**	**30.55**	**0.07**	**0.475**	**0.065**	**0.000**	**0.097**	**0.050**	**0.757**	**0.147**		

Table 4-9 Dwyka Tillite: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D53D	28.58	0	0.008	0.008	0.04734			Low
D53G	28.94	0	0.018	0.018	0.07434			Intermediate
D54D	73.18	0	0.023	0.023	1.52209			Low
D54G	48.52	0	0.048	0.048	2.67637			Low
D57E	32.25	0	0.012	0.012	0.35986			Low
D62B	94.18	0	0.010	0.010	1.64851			Low
D62H	70.15	0	0.005	0.005	1.33939			Low

Table 4-10 Dwyka Tillite: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D53D	0	2	1	8	6	0	12	6	47	35	18
D53G	0	2	5	6	21	0	6	15	18	62	21
D54D	0	15	12	13	17	0	26	21	23	30	47
D54G	4	27	45	38	86	2	14	23	19	43	38
D57E	0	0	1	6	1	0	0	13	75	13	13
D62B	0	63	30	11	16	0	53	25	9	13	78
D62H	5	33	36	18	13	5	31	34	17	12	70

4.3.4 Ecca Carbonaceous Shale

The GRU consists of dry rangeland. The Sak and the Hartbees River, which are ephemeral, cut through the western portion, and the Brak cuts through the eastern portion (Figures 4.13 and 4.14).

The Ecca carbonaceous shales overlie Dwyka Tillites and are extensively intruded by dolerite sheets. It is also divided into a western and eastern sector based on rainfall and recharge. Recharge is less than 1 mm/a, except in the eastern portion where rainfall is higher. Borehole yields also vary across the GRU, being 0.6 - 0.8 l/s in the west and 0.8 - 1.0 l/s in the east. Groundwater levels are from 15 - 25 mbgl.

Groundwater quality is poor and of Class 3. Nitrates and arsenic are frequently of concern in the west, and nitrates in the east. The potability of groundwater is poor to unacceptable in the west, and good in the east. 70 - 90% of boreholes are potable in the east, whereas potability drops to less 15% towards the west (Table 4.13).

The aquifer is not utilised for municipal water supply. Groundwater use is for primarily for livestock watering, small-scale local water supply and Schedule 1 water use (Table 4.11), except for D53F in the west where salt mining takes place. The stress index is low except in D53F, where it exceeds 1. No groundwater level data are available.

All catchments have a stress index of below 0.3 except D53F, and groundwater dependency for water supply is high, except with for D53G and D57E, where poor groundwater quality precludes its use for water supply. Consequently, the priority of all catchments in the GRU is low, except for D53F, which is considered intermediate due to only a moderate dependence for water supply (Table 4.12).

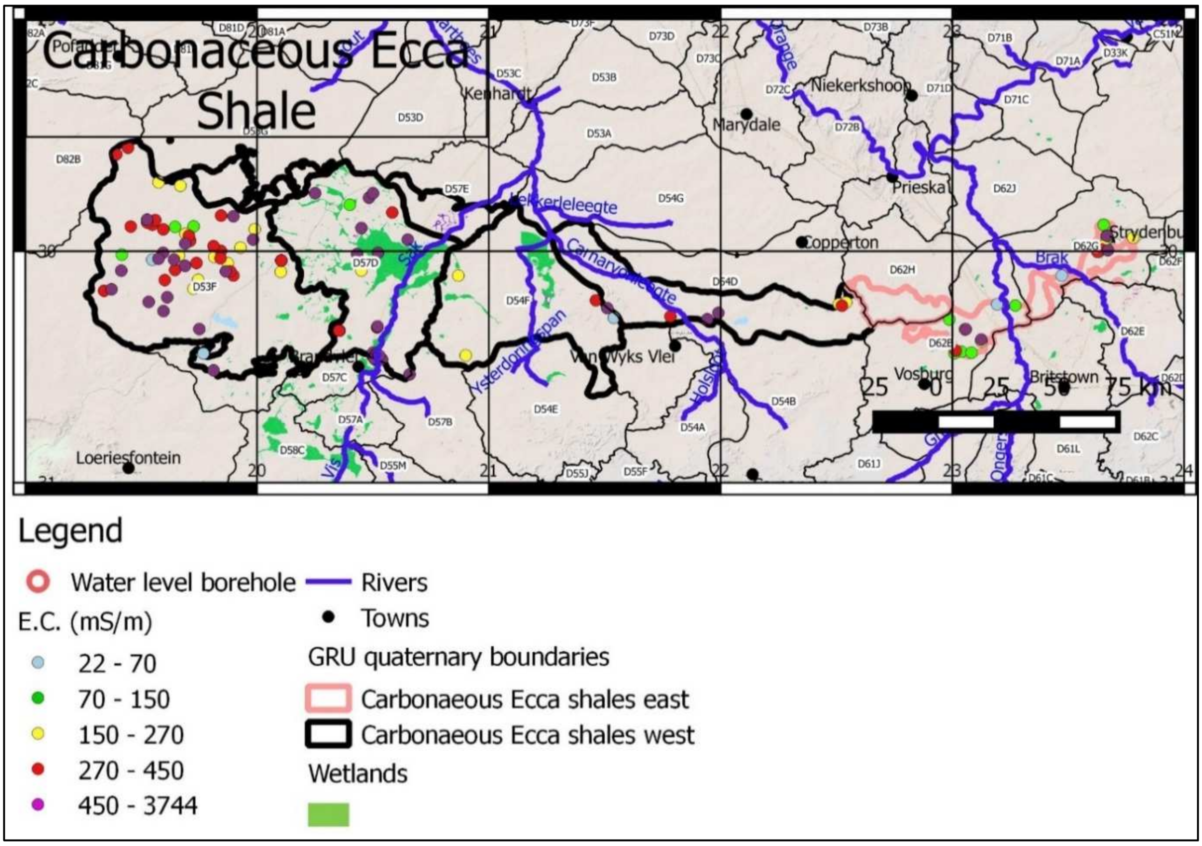


Figure 4.13 Catchments in Carbonaceous Ecca Shales GRU and existing monitoring boreholes

Figure 4.14 Carbonaceous Ecca Shales land cover

Table 4-11 Carbonaceous Ecca Shales: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D53F	90	88	7051	0.81	0.068	0.003	0.500	0.577	0.034	0.007	1.188	0.041	1.47	F
D53G	99	15	726	0.11		0.027			0.005	0.000	0.032	0.005	0.30	C
D54D	173	53	2698	2.87	0.083	0.147			0.020	0.012	0.262	0.032	0.09	B
D54F	161	100	3809	2.93	0.000	0.202	0.000	0.000	0.028	0.001	0.231	0.029	0.08	B
D57D	138	100	4444	1.85	0.119	0.104	0.000	0.000	0.044	0.097	0.364	0.141	0.20	B
D57E	145	38	740	0.37	0.000	0.028	0.000	0.000	0.006	0.017	0.051	0.023	0.14	B
D62B	221	18	560	2.38	0.020	0.036	0.000	0.000	0.007	0.000	0.064	0.007	0.03	A
D62G	256	20	517	3.27	0.000	0.035	0.000	0.000	0.032	0.000	0.067	0.032	0.02	A
D62H	216	26	527	2.22		0.028			0.004	0.000	0.032	0.004	0.01	A
Total			**21071**	**16.80**	**0.289**	**0.611**	**0.500**	**0.577**	**0.179**	**0.134**	**2.290**	**0.314**		

Table 4-12 Carbonaceous Ecca Shales: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D53F	51.46	0	0.044	0.044	**-0.25***			Intermediate
D53G	28.94	0	0.006	0.006	0.05			Low
D54D	73.18	0	0.026	0.026	1.69			Low
D54F	89.19	0	0.036	0.036	1.75			Low
D57D	92.00	0	0.057	0.057	0.96			Low
D57E	32.25	0	0.007	0.007	0.21			Low
D62B	94.18	0	0.009	0.009	1.50			Low
D62G	95.21	0	0.041	0.041	2.08			Low
D62H	70.15	0	0.006	0.006	1.42			Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Table 4-13 Carbonaceous Ecca Shale: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D53F	3	3	13	23	17	5	5	22	39	29	32
D53G	0	2	5	6	21	0	6	15	18	62	21
D54D	0	15	12	13	17	0	26	21	23	30	47
D54F	1	0	2	1	1	20	0	40	20	20	60
D57D	0	1	2	6	18	0	4	7	22	67	11
D57E	0	0	1	6	1	0	0	13	75	13	13
D62B	0	63	30	11	16	0	53	25	9	13	78
D62G	3	40	19	4	5	4	56	27	6	7	87
D62H	5	33	36	18	13	5	31	34	17	12	70

4.3.5 Ecca Sandstone and Shale West

The GRU consists of dry rangeland, which drains to an extensive network of saline pans, not all of which are connected to the Vis and Sak rivers draining the GRU (Figures 4.15 and 4.16).

The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of 0.5 - 1 mm/a. The aquifer is of the fractured type and mean borehole yields are 0.8 - 1 l/s. Groundwater levels are shallow and are 10 - 15 mbgl.

Groundwater quality is Good to Marginal and of Class 1 - 2 although Nitrates and Fluoride can be of concern. The potability of groundwater is variable and declines towards the north near the vicinity of Pans. Potability of groundwater in catchments rages from 17 to 100% (Table 4.16).

The aquifer is a sole source aquifer and the town of Brandvlei relies on the aquifer. Groundwater use is for livestock watering, and small-scale local water supply, of which Brandvlei is the most significant. The high registered water usage for irrigation in D57A cannot be observed (Figure 4.16). One of the allocations for irrigation is for water services to Brandvlei. A significant industrial water use is registered by the National Research Foundation in D54E (Table 4.14). The stress index is low, except for D57A, if the irrigation allocation were to be used. Groundwater levels have dropped 3 - 4 m in D57A and B (Figure 4.17), but appear to remain stable.

Catchments with a high stress index (>0.65) were considered of high priority since groundwater dependency in the GRU is very high and the stressed catchments are associated with water supply to Brandvlei (Table 4.15).

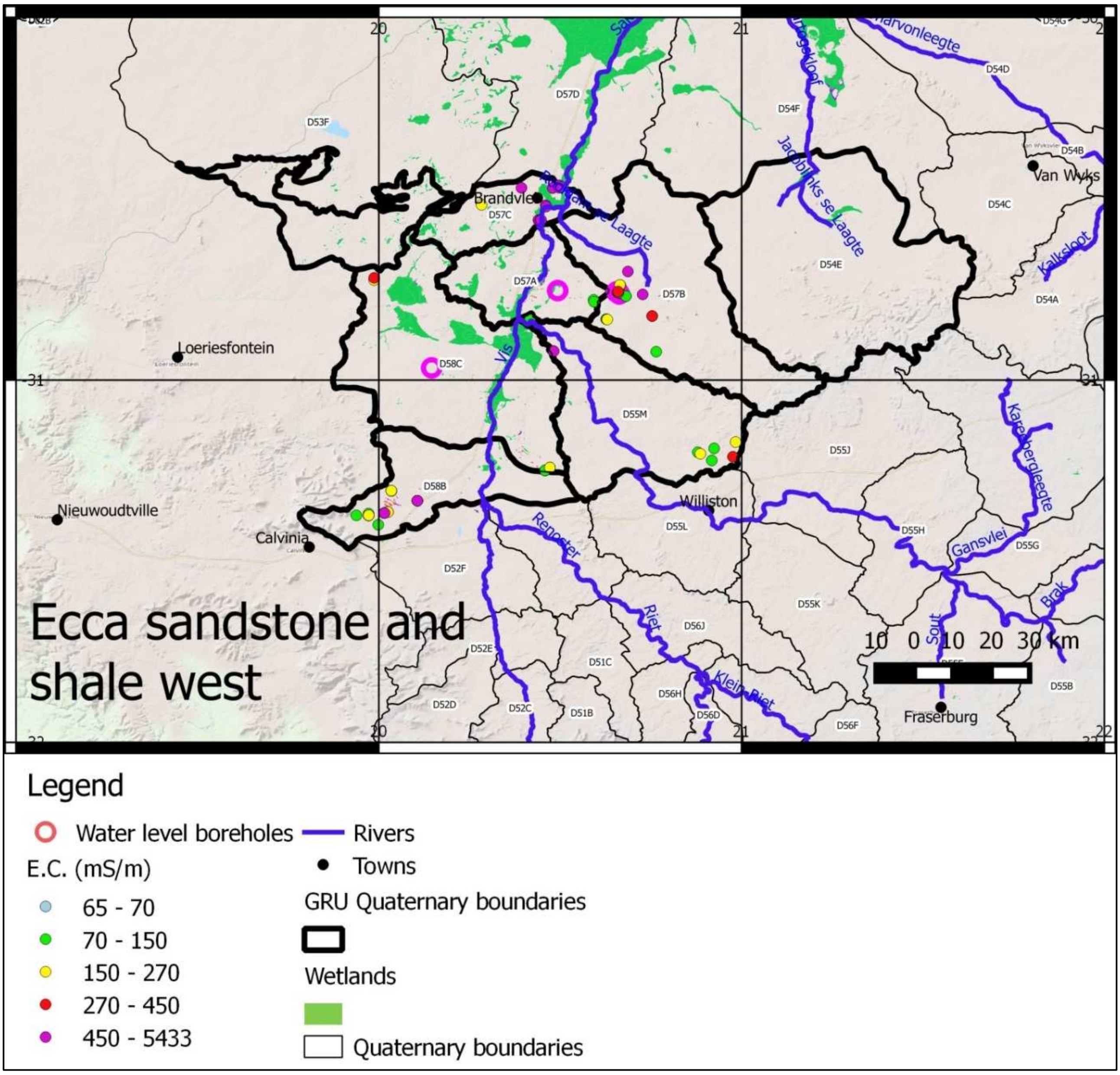


Figure 4.15 Catchments in Ecca Sandstone and Shale West GRU and existing monitoring boreholes

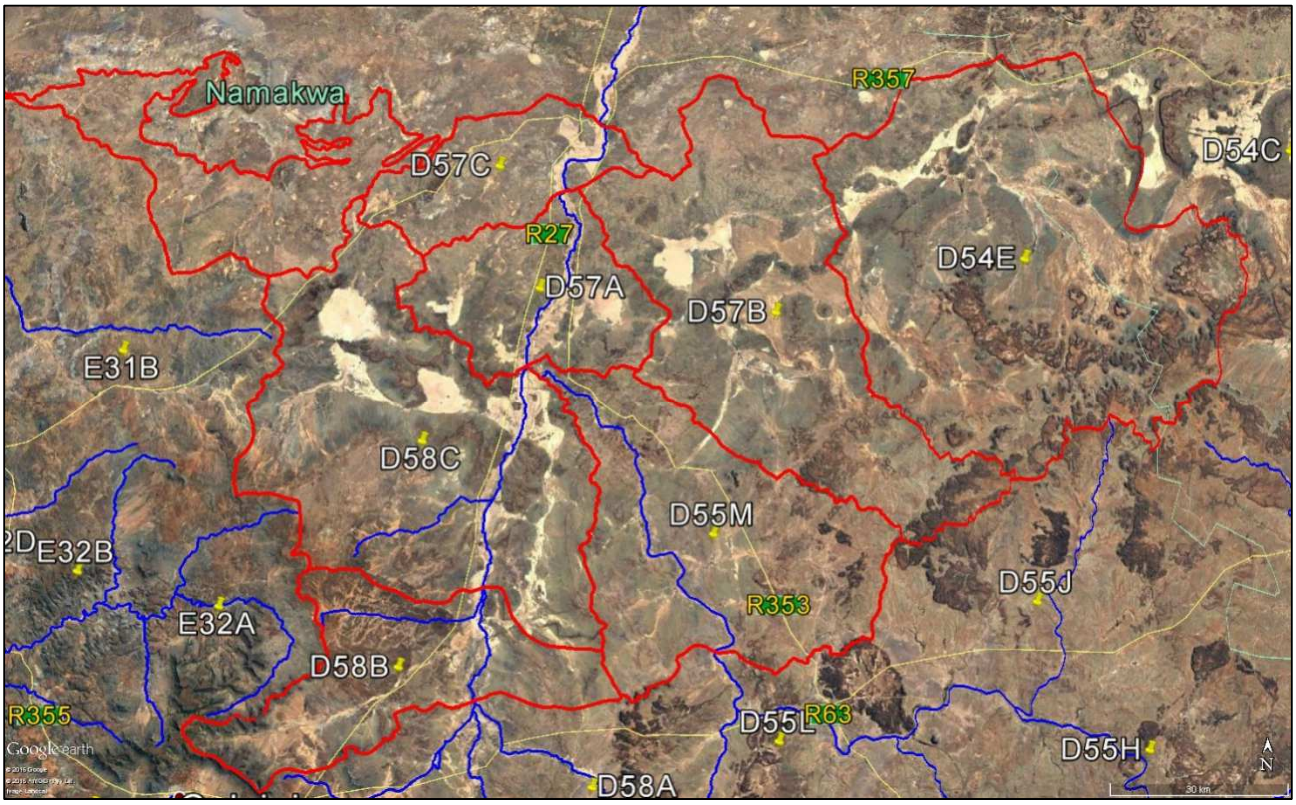


Figure 4.16 Ecca Sandstone and Shale West land cover

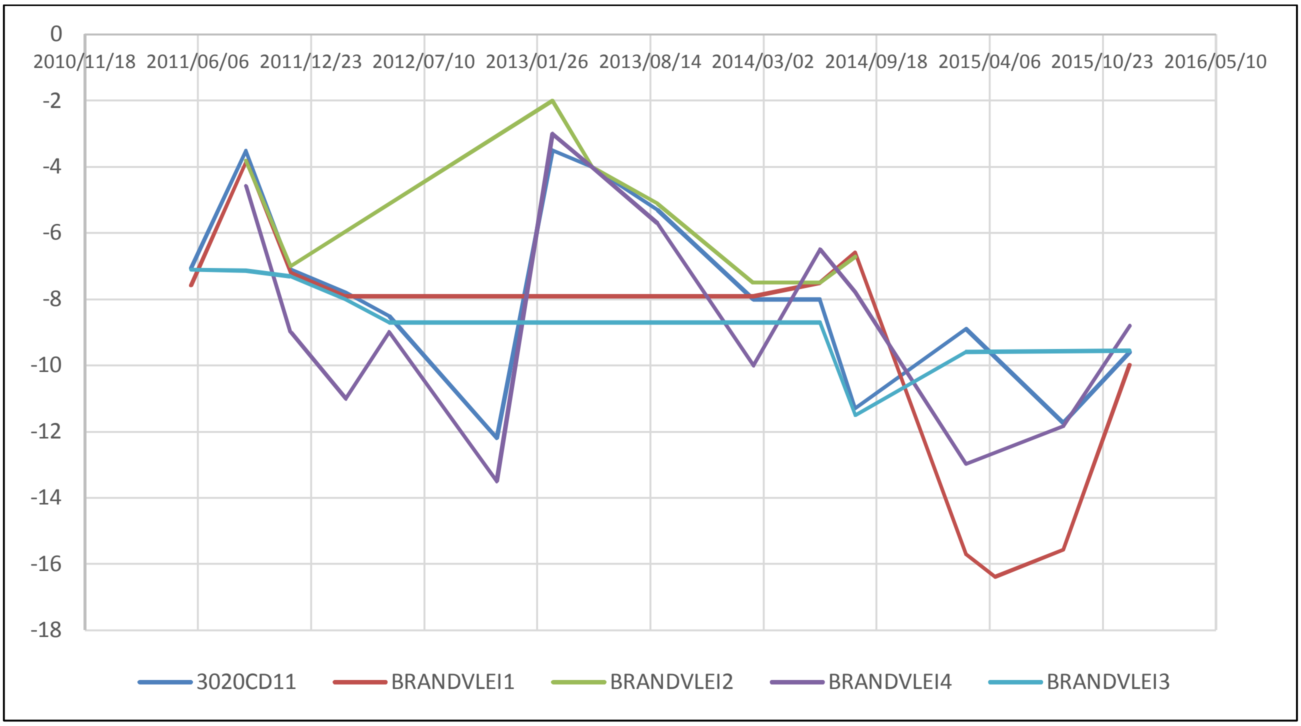


Figure 4.17 Groundwater levels in D57A (3020CD11) and D57B (Brandvlei) in mbgl

Table 4-14 Ecca Sandstone and Shale West: Groundwater use and stress index

Quat	MAP	%of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D53F	90	12	986	0.11		0.0005			0.005	0.000	0.005	0.005	0.05	A
D54E	163	100	3326	2.70	0.011	0.104	0.000	0.119	0.023	0.001	0.257	0.024	0.10	B
D55M	143	100	1813	0.86	0.018	0.049	0.000	0.000	0.012	0.000	0.080	0.013	0.09	B
D57A	126	100	853	0.26	0.207	0.009	0.000	0.000	0.006	0.000	0.222	0.006	0.86	E
D57B	147	100	2274	2.40	0.054	0.099	0.000	0.000	0.016	0.000	0.169	0.016	0.07	B
D57C	126	100	637	0.19	0.000	0.001	0.000	0.000	0.007	0.137	0.145	0.144	0.75	E
D58B	163	100	1131	1.71	0.000	0.001	0.000	0.000	0.010	0.014	0.025	0.024	0.01	A
D58C	136	100	2520	0.99	0.079	0.001	0.000	0.000	0.018	0.001	0.099	0.020	0.10	B
Total			**13539**	**9.23**	**0.368**	**0.263**	**0.000**	**0.119**	**0.098**	**0.154**	**1.001**	**0.251**		

Table 4-15 Ecca Sandstone and Shale West: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D53F	51.46	0	0.01	0.01	0.069			Low
D54E	90.57	0	0.03	0.03	1.585			Low
D55M	92.14	0	0.02	0.02	0.506			Low
D57A	91.98	0	0.01	0.01	0.022	Y	3	High
D57B	92.15	0	0.02	0.02	1.447	Y	4	Low
D57C	97.94	0	0.01	0.01	0.029			High
D58B	94.88	0	0.01	0.01	1.095			Low
D58C	91.90	0	0.02	0.02	0.578			Low

Table 4-16 Ecca Sandstone and Shale West: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D53F	3	3	13	23	17	5	5	22	39	29	32
D54E											
D55M	0	4	2	1	1	0	50	25	13	13	75
D57A	0	2	0	0	0	0	100	0	0	0	100
D57B	0	10	3	1	2	0	63	19	6	13	81
D57C	0	1	1	0	10	0	8	8	0	83	17
D58B	0	5	7	2	0	0	36	50	14	0	86
D58C	0	2	1	1	0	0	50	25	25	0	75

4.3.6 Ecca Sandstone and Shale Central and Southwest

The GRU consists of dry rangeland that drains to the Vis and Sak rivers and the Carnarvonleegte (Figures 4.18 and 4.19).

The Ecca sandstones and shales overlie the carbonaceous shales and have a recharge of from 1 - 3.5 mm/a, increasing towards the east. The aquifer is of the fractured type and mean borehole yields are 1 - 2 l/s. Groundwater levels are shallow and 10 - 15 mbgl.

Groundwater quality is highly variable but generally of Class 1 - 2, although fluoride and arsenic can be of concern. There is no natural source of arsenic in sandstone, and a potential source could be the upwelling of deeper groundwater. The potability of groundwater is variable and declines from nearly 100% to 50% towards the north and west (Table 4.19).

The towns of Carnarvon, Van Wyks Vlei and Willistion are dependent on the aquifer. Groundwater use is for small-scale irrigation near the main ephemeral rivers, livestock watering, and small scale to moderate size local water supply. A significant industrial water use is registered by Carnarvon in D54B (Table 4.17). The stress index is low, except for D55L due to abstraction by Williston and for significant irrigation. Groundwater levels have dropped 15 m in D54B (Figure 4.20) and continue to drop. This suggests localised over abstraction could be occurring near Carnarvon in D54B. Water levels near Williston in D55L appear to remain stable but have dropped from 5 - 10 m (Figure 4.22).

The GRU is highly dependent on groundwater for water supply. Catchments with an observed decline in water level and moderate to the moderately high stress index (0.56) were considered priority catchments (Table 4.18). D54B was considered of high priority due to the observed water level decline and D55L due to the moderately high groundwater use.

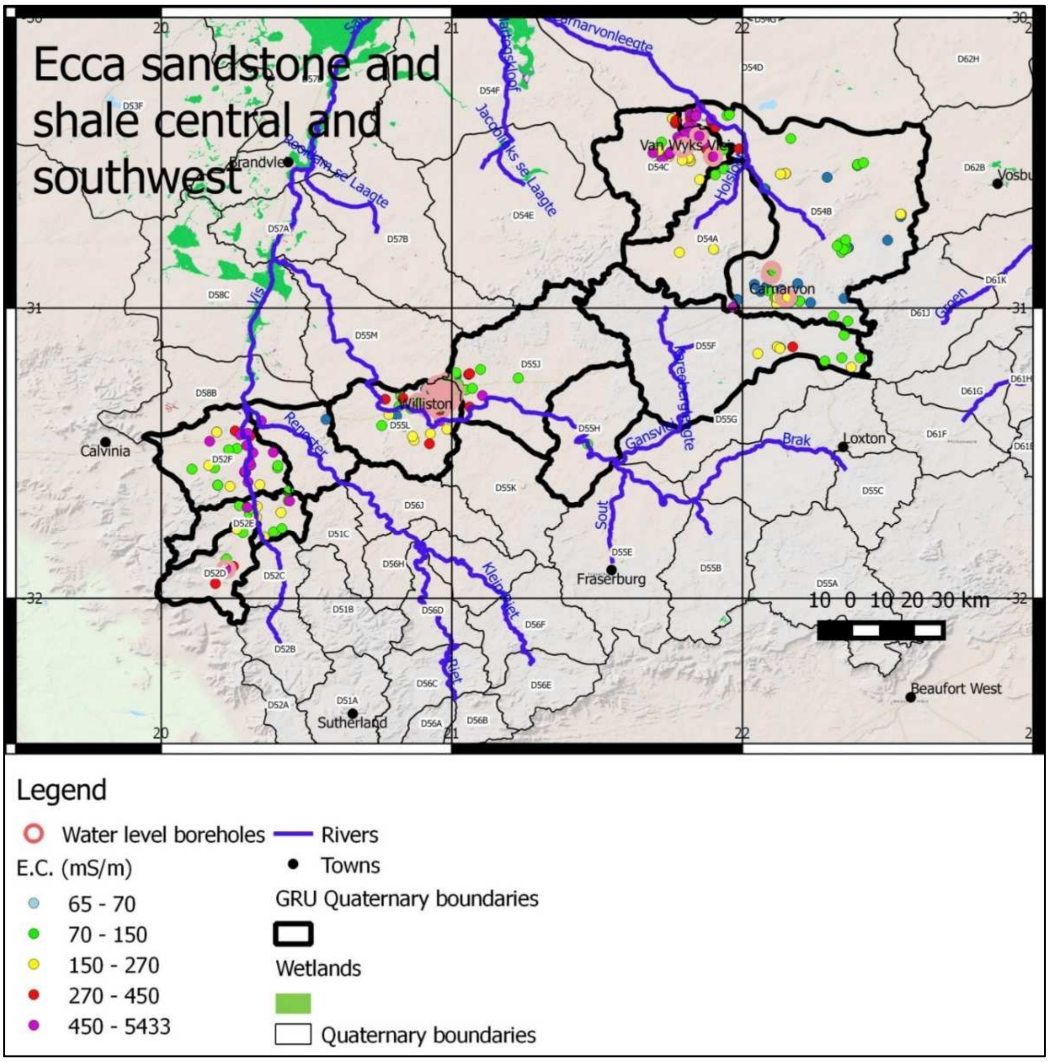


Figure 4.18 Catchments in Ecca Sandstone and Shale Central and Southwest GRU and existing monitoring boreholes

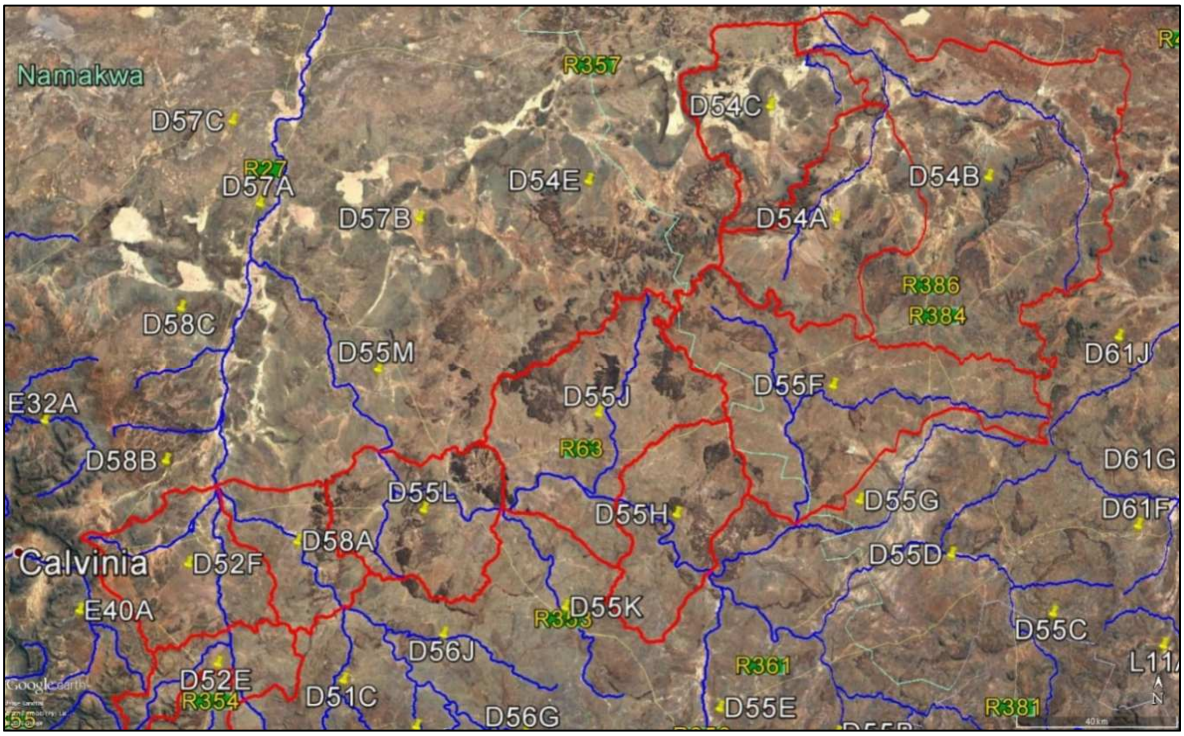


Figure 4.19 Ecca Sandstone and Shale Central and Southwest land cover

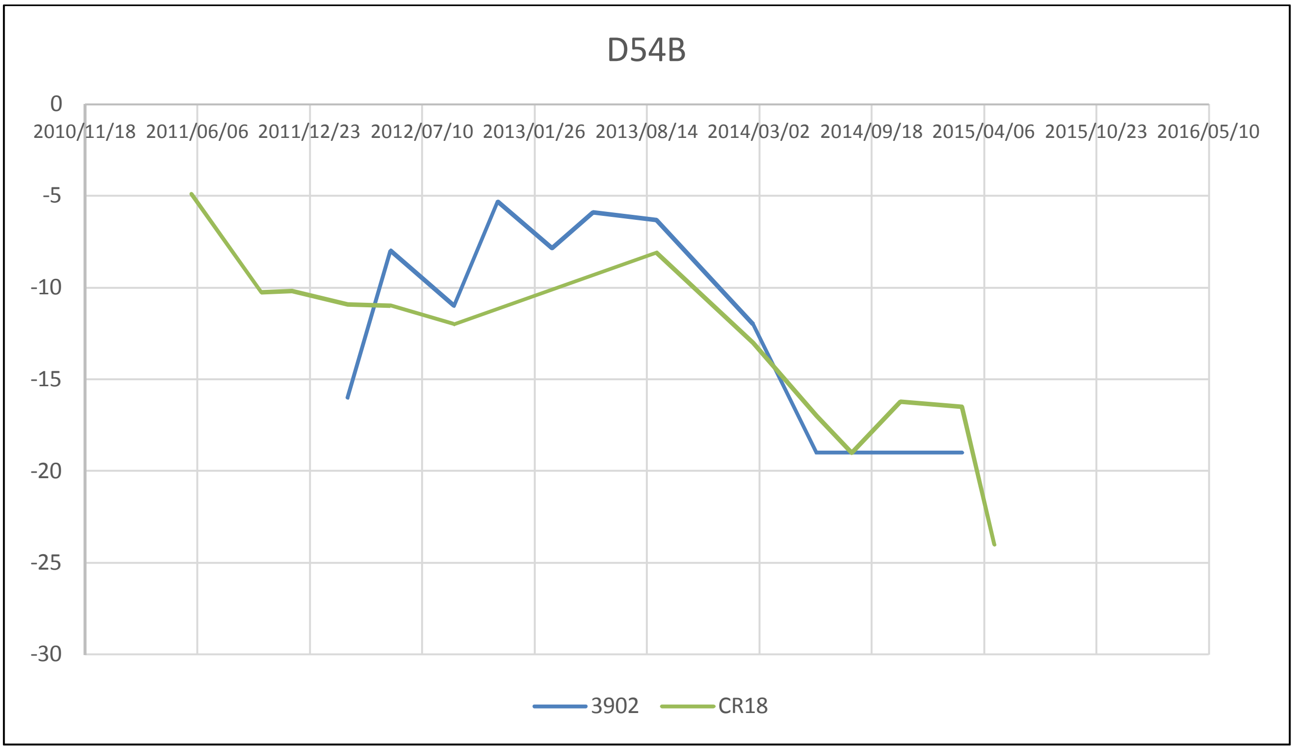


Figure 4.20 Water levels in D54B in mbgl

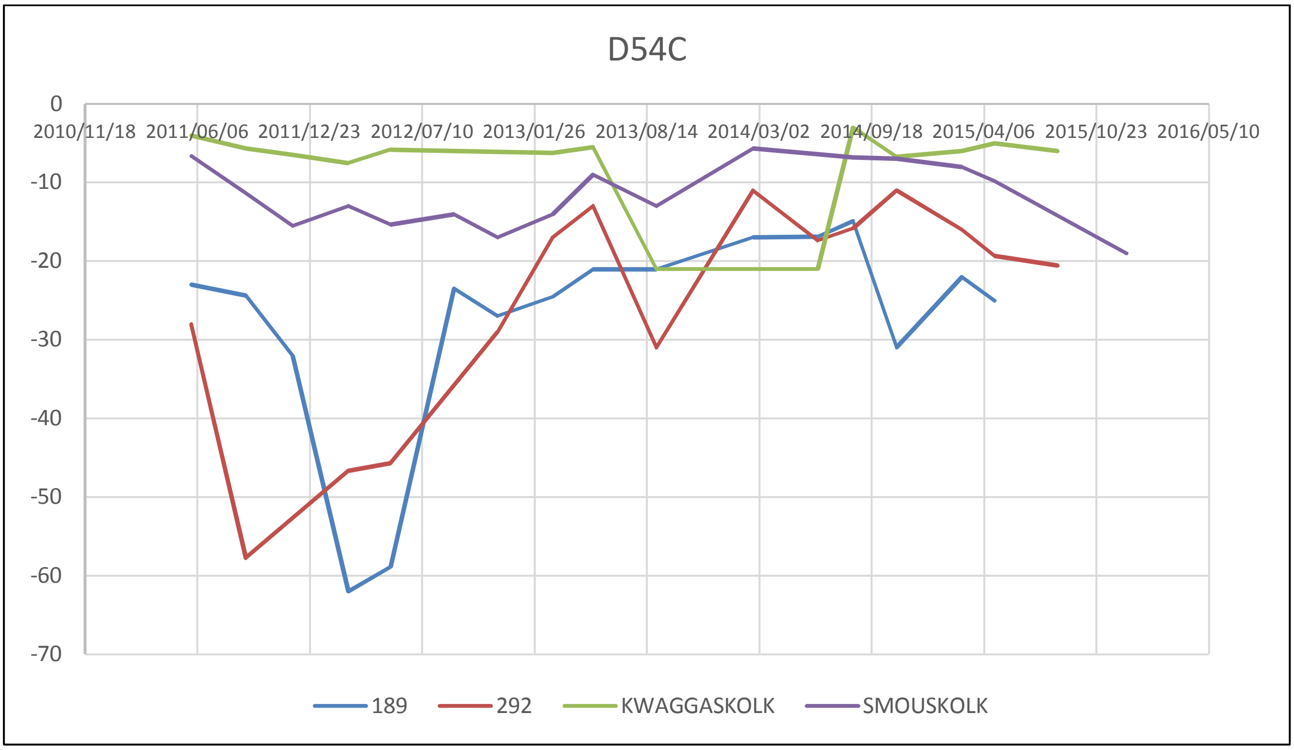


Figure 4.21 Water levels in D54C in mbgl

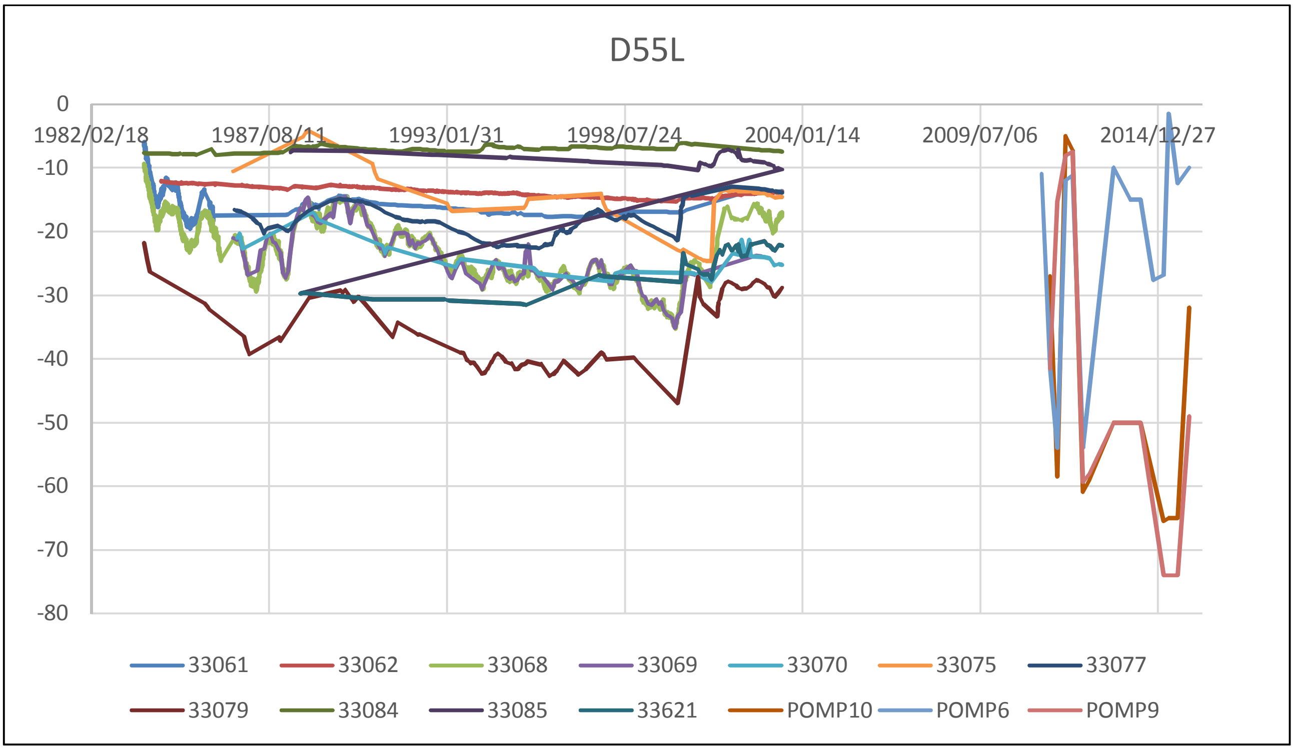


Figure 4.22 Water levels in D55L in mbgl

Table 4-17 Ecca Sandstone and Shale Central and Southwest: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D52D	246	100	638	2.63	0.076	0.004	0.000	0.000	0.005	0.000	0.085	0.005	0.03	A
D52E	194	100	609	1.84	0.279	0.002	0.000	0.000	0.004	0.000	0.286	0.005	0.16	B
D52F	162	100	1146	1.90	0.000	0.000	0.000	0.000	0.008	0.001	0.009	0.009	0.00	A
D54A	177	100	1518	1.82	0.000	0.099	0.000	0.000	0.011	0.000	0.111	0.011	0.06	B
D54B	191	100	4051	6.97	0.702	0.264	0.000	0.327	0.052	0.485	1.830	0.537	0.26	C
D54C	155	100	1342	0.88	0.000	0.088	0.000	0.000	0.010	0.100	0.198	0.110	0.22	C
D55F	176	100	2631	4.48	0.087	0.158	0.000	0.000	0.025	0.001	0.271	0.026	0.06	B
D55H	158	100	1151	1.33	0.068	0.047	0.000	0.000	0.008	0.000	0.123	0.008	0.09	B
D55J	162	100	1998	2.63	0.027	0.005	0.000	0.000	0.014	0.000	0.046	0.014	0.02	A
D55L	156	100	1242	1.71	0.684	0.035	0.000	0.000	0.016	0.221	0.956	0.237	0.56	D
D58A	144	100	763	0.77	0.036	0.000	0.000	0.000	0.006	0.000	0.042	0.006	0.06	B
Total				**29.46**	**1.959**	**0.702**	**0.000**	**0.327**	**0.159**	**0.809**	**3.956**	**0.969**		

Table 4-18 Ecca Sandstone and Shale Central and Southwest: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D52D	91.86	0	0.006	0.006	1.651			Low
D52E	91.86	0	0.006	0.006	1.009			Low
D52F	91.86	0	0.011	0.011	1.231			Low
D54A	86.69	0	0.015	0.015	1.109			Low
D54B	97.85	0	0.068	0.068	3.334	N	15	High
D54C	86.69	0	0.013	0.013	0.442	Y	0	Intermediate
D55F	87.21	0	0.032	0.032	2.734			Low
D55H	92.15	0	0.010	0.010	0.781			Low
D55J	92.15	0	0.018	0.018	1.677			Low
D55L	98.84	0	0.021	0.021	0.489	y	10	High
D58A	91.92	0	0.007	0.007	0.470			Low

Table 4-19 Ecca Sandstone and Shale Central and Southwest: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D52D	0	2	2	3	1	0	25	25	38	13	50
D52E	0	7	4	0	2	0	54	31	0	15	85
D52F	1	7	5	2	12	4	26	19	7	44	48
D54A	0	2	2	0	1	0	40	40	0	20	80
D54B	22	35	13	4	12	26	41	15	5	14	81
D54C	1	17	21	4	18	2	28	34	7	30	64
D55F	0	5	4	1	0	0	50	40	10	0	90
D55H	0	1	0	0	0	0	100	0	0	0	100
D55J	2	6	0	3	1	17	50	0	25	8	67
D55L	17	24	6	5	1	32	45	11	9	2	89
D58A	1	0	0	0	1	50	0	0	0	50	50

4.3.7 Ecca Sandstone and Shale East

The GRU consists of dry rangeland drained by the Brak and Ongers rivers (Figures 4.23 and 4.24). Pans exist in a belt extending from Vosburg to Strydenburg, which drain groundwater via evaporation.

The Ecca sandstones and shales overlie the carbonaceous shales. They have a recharge of from 4 - 11 mm/a, increasing from west east of Britstown due to increasing rainfall. The aquifer is of the fractured type and mean borehole yields are between1 - 2 l/s. Groundwater levels are shallow and 7 - 15 mbgl.

Groundwater quality is Good and of Class 1, although arsenic can be of concern. There is no natural source of arsenic in sandstone, and a potential source could be the upwelling of deeper groundwater. Groundwater potability is more than 80% (Table 4.22).

The towns of Strydenburg, Britstown and Vosburg depend on the aquifer. Groundwater use is largely for small-scale irrigation near the main ephemeral rivers, livestock watering, and moderate size local water supply supplying the main towns in the GRU (Table 4.20). The stress index is low and below 0.06 in all catchments. Groundwater levels are stable (Figures 4.25 to 4.27) and only in D62G, in the Strydenburg vicinity, has a water level decline of 5 m been observed (Figure 4.28). This suggests localised over-abstraction could be occurring.

The GRU is highly dependent on groundwater for water supply. D62G was considered of intermediate priority due to the observed water level decline near Strydenburg (Table 4.21).

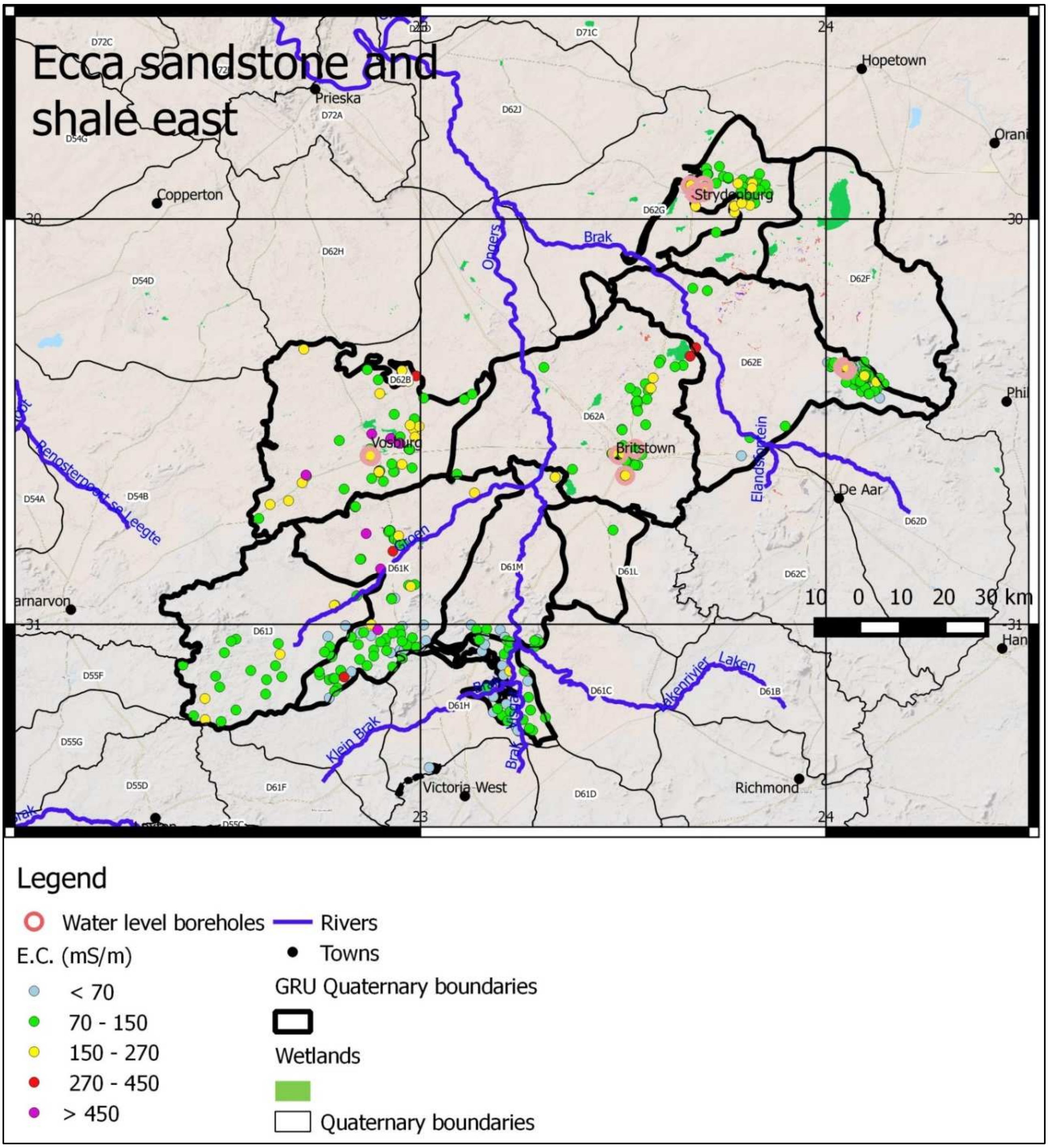


Figure 4.23 Catchments in Ecca Sandstone and Shale East GRU and existing monitoring boreholes

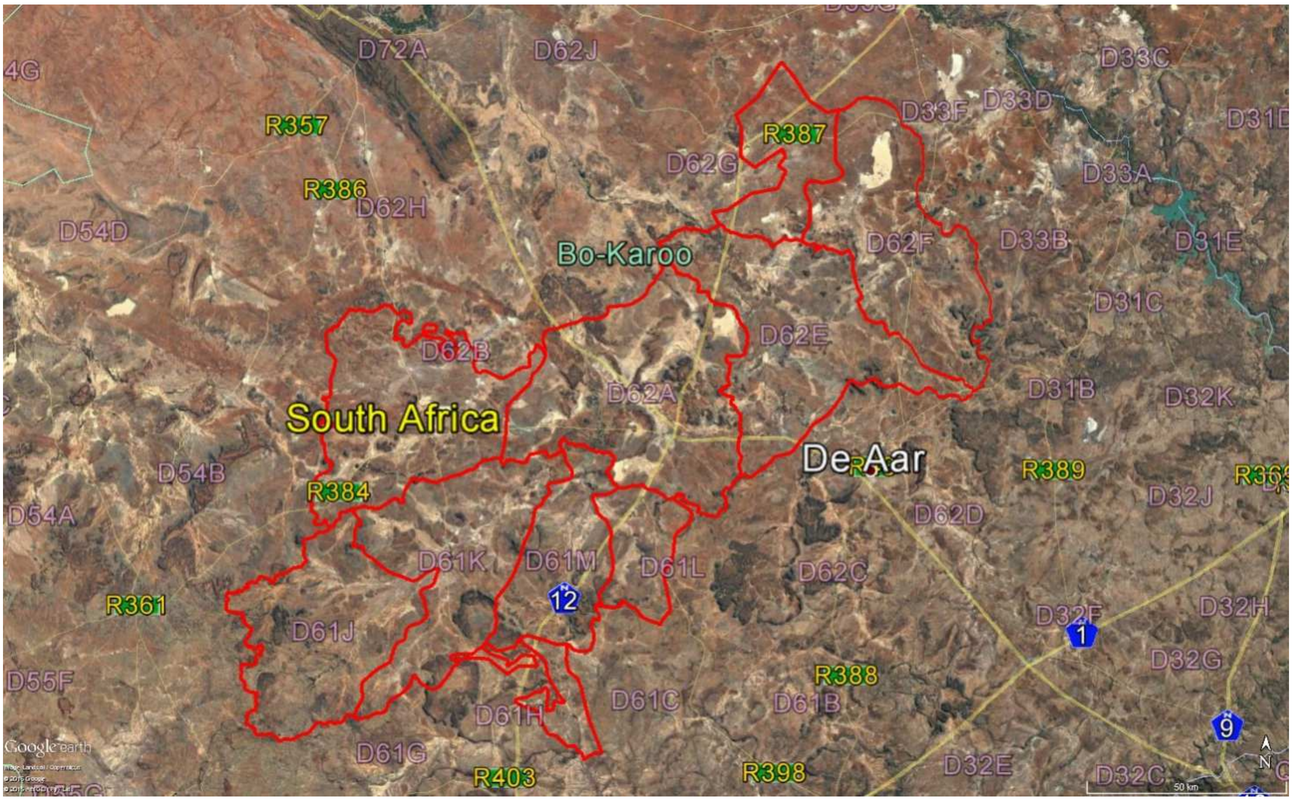


Figure 4.24 Ecca Sandstone and Shale East land cover

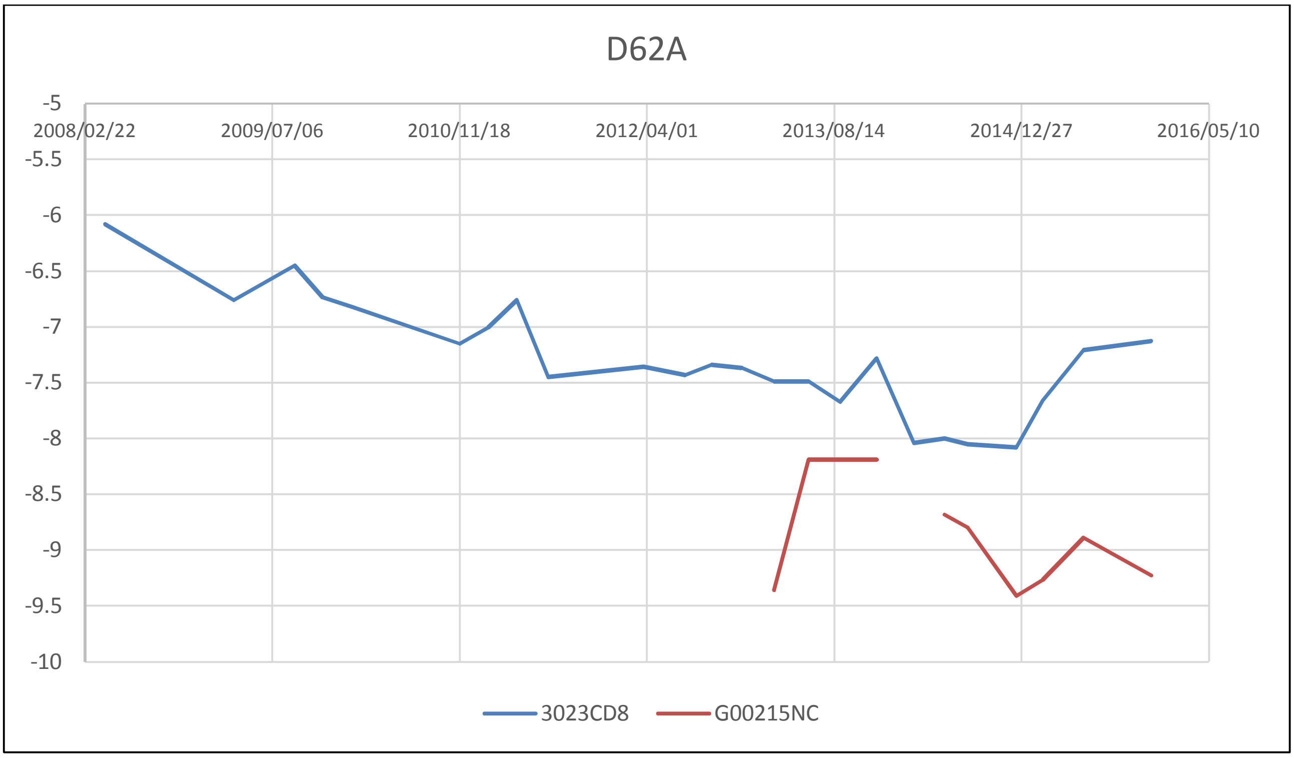


Figure 4.25 Water levels in D62A in mbgl

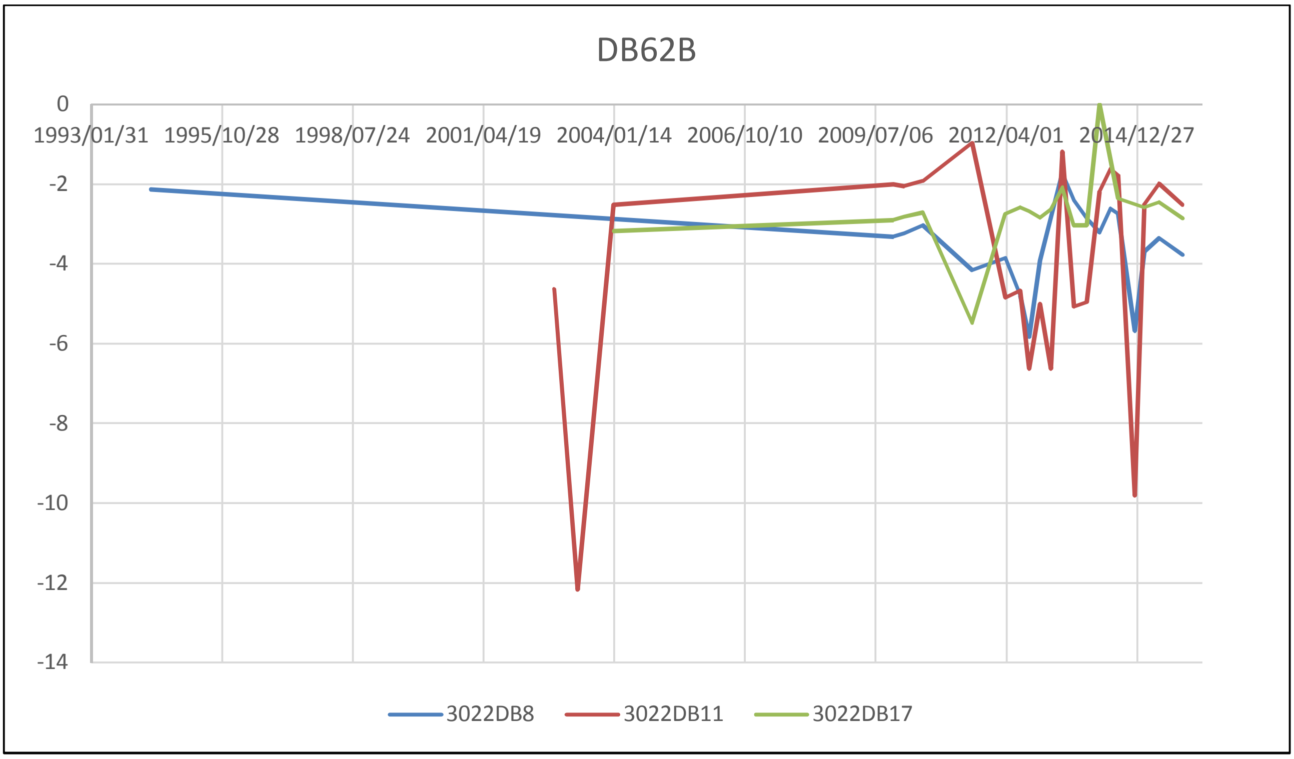


Figure 4.26 Water levels in D62B in mbgl

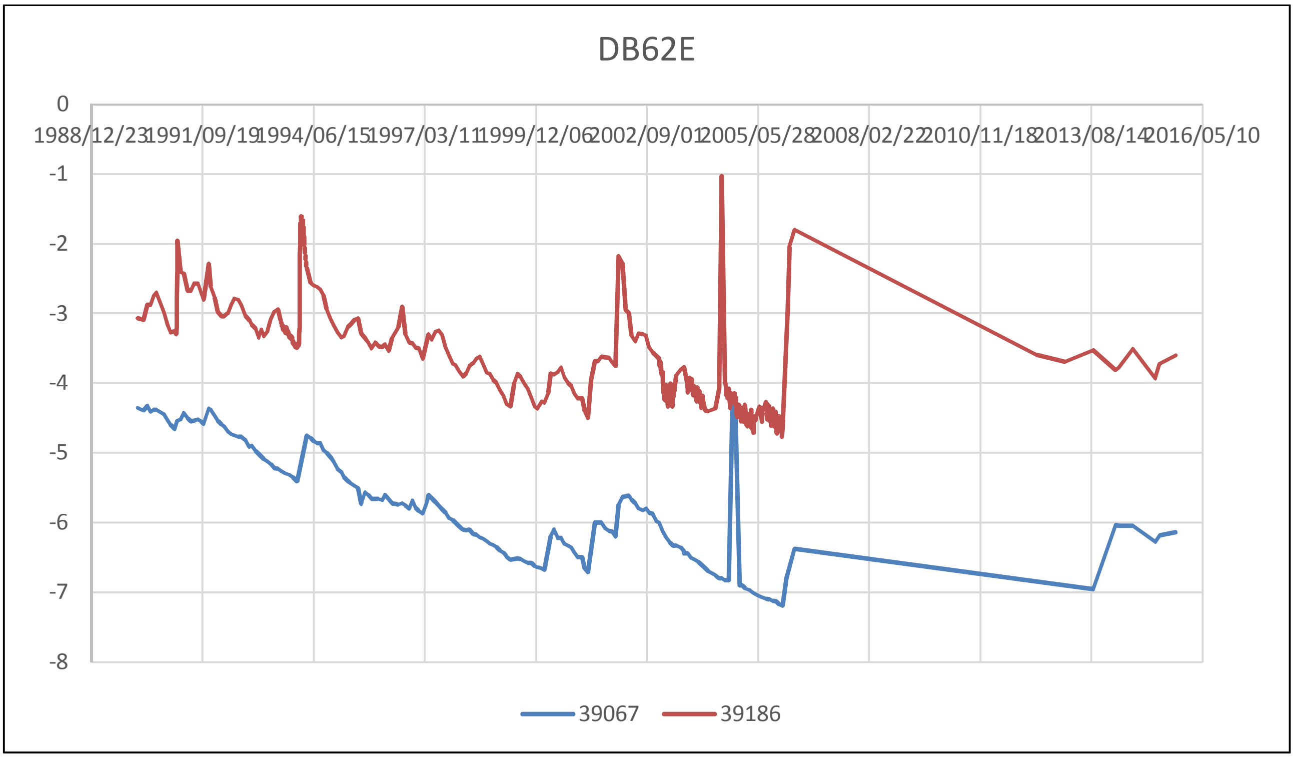


Figure 4.27 Water levels in D62E in mbgl

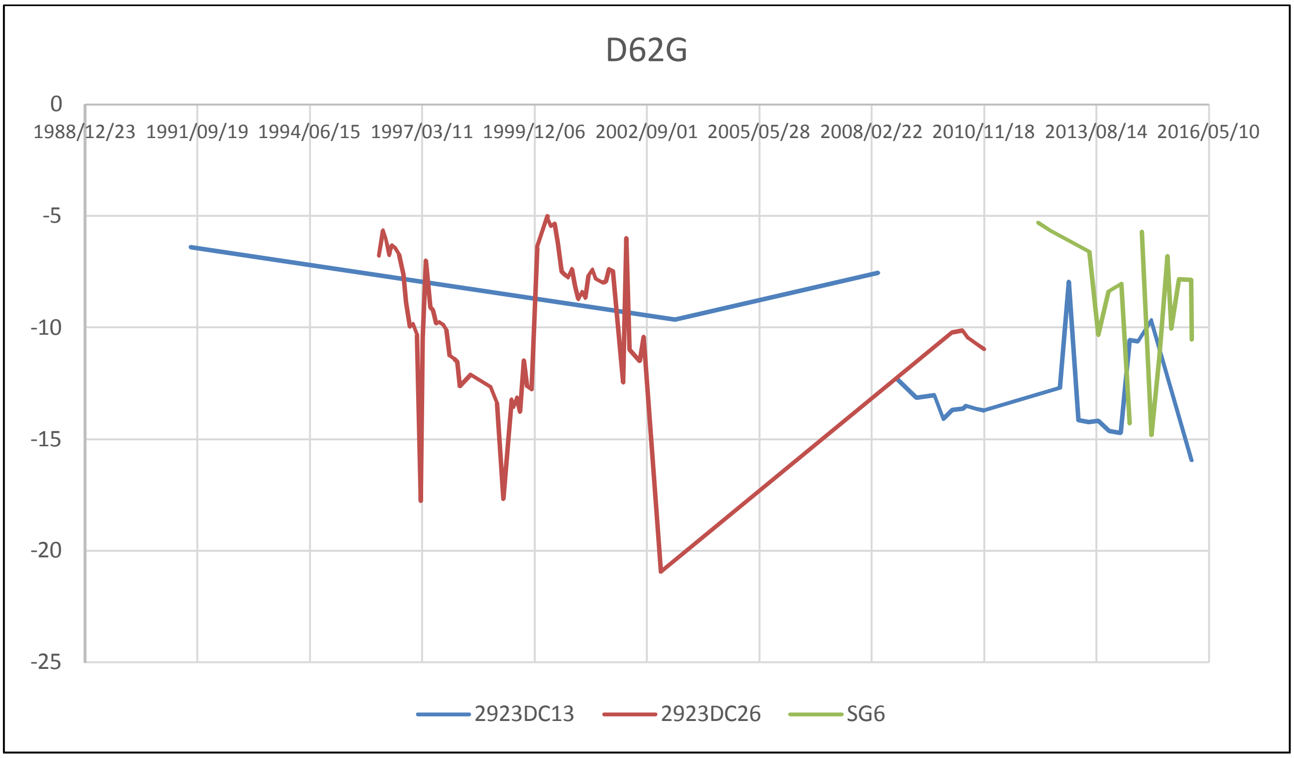


Figure 4.28 Water levels in D62G in mbgl

Table 4-20 Ecca Sandstone and Shale East: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D61H	231	28	300	1.46		0.022	0.000	0.000	0.003	0.000	0.026	0.004	0.02	A
D61J	215	100	1557	5.99	0.184	0.102	0.000	0.000	0.015	0.000	0.302	0.016	0.05	B
D61K	227	100	1607	7.54	0.050	0.109	0.000	0.000	0.016	0.000	0.175	0.016	0.02	A
D61L	270	50	504	3.71	0.020	0.033	0.000	0.000	0.006	0.000	0.059	0.006	0.02	A
D61M	252	100	942	5.88	0.124	0.064	0.000	0.000	0.011	0.000	0.199	0.011	0.03	A
D62A	248	100	2240	11.71	0.134	0.147	0.000	0.000	0.060	0.349	0.690	0.409	0.06	B
D62B	221	62	1934	8.22		0.126			0.025	0.146	0.296	0.171	0.04	A
D62E	273	100	1920	15.51	0.359	0.173	0.000	0.000	0.024	0.001	0.556	0.024	0.04	A
D62F	290	100	1698	19.42	0.257	0.201	0.000	0.000	0.022	0.001	0.482	0.023	0.02	A
D62G	256	32	812	5.14	0.026	0.056			0.050	0.146	0.277	0.196	0.05	B
Total			**13515**	**84.58**	**1.153**	**1.031**	**0.000**	**0.000**	**0.232**	**0.644**	**3.060**	**0.875**		

Table 4-21 Ecca Sandstone and Shale East: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D61H	86.42	0	0.004	0.004	0.935			Low
D61J	86.51	0	0.020	0.020	3.696			Low
D61K	87.45	0	0.020	0.020	4.787			Low
D61L	90.36	0	0.008	0.008	2.371			Low
D61M	89.54	0	0.015	0.015	3.688			Low
D62A	97.51	0	0.078	0.078	7.150	Y	1	Low
D62B	94.18	0	0.027	0.027	5.146	Y	2	Low
D62E	90.76	0	0.031	0.031	9.717	y	1	Low
D62F	86.28	0	0.028	0.028	12.305			Low
D62G	95.21	0	0.059	0.059	3.156	y	5	Intermediate

Table 4-22 Ecca Sandstone and Shale East: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D61H	57	59	11	6	2	42	44	8	4	1	94
D61J	2	20	4	0	0	8	77	15	0	0	100
D61K	15	47	4	2	3	21	66	6	3	4	93
D61L	13	7	0	1	0	62	33	0	5	0	95
D61M	4	6	1	0	0	36	55	9	0	0	100
D62A	4	36	5	1	0	9	78	11	2	0	98
D62B	0	63	30	11	16	0	53	25	9	13	78
D62E	7	49	5	1	0	11	79	8	2	0	98
D62F	0	3	0	0	0	0	100	0	0	0	100
D62G	3	40	19	4	5	4	56	27	6	7	87

4.3.8 Far Northwestern Coastal Hinterland

The GRU consists of the very dry desert region of coastal mountains and small catchments that drain directly to the sea. D82K and D82L are bound by the lower Orange where it flows into the Atlantic Ocean (Figures 4.29 and 4.30).

The Gariep belt, extensively covered by Tertiary and Quaternary sediments, underlies the Far Northwestern Coastal Hinterland. It has recharge of less than 1 mm/a. The fractured aquifer is classified as poor, with borehole yields being low and around 0.1 l/s. Groundwater levels are from 25 - 45 mbgl.

Groundwater is of Poor to Unacceptable quality, Class 3 and 4, with high Fluoride levels. Groundwater is of poor quality, except adjacent to the Orange River. This indicates recharge of fresh water from the river. The high salinity precludes groundwater use over large parts of the GRU. The potability is less than 15% in the southern half of the GRU (Table 4.25).

Groundwater dependency is low on the coast and close to the margins of the Orange River, but increases inland. The towns of Sanddrift, Port Nolloth, Kuboes and Lekkersing are dependent on groundwater. Groundwater use is primarily for water supply, of which Port Nolloth is the main groundwater user (Table 4.23). Additional groundwater use for livestock. The stress index is high due to the very low recharge rates. D82K and F20D have very high stress indices, however, the aquifers utilised are likely recharged by surface water during flood events, and hence rainfall recharge is not a good indicator of recharge to the aquifers. Groundwater levels in F20D do not indicate stress and have risen from 1984 to present (Figure 4.31).

The GRU is only marginally dependent on groundwater for water supply due to the poor quality; consequently, the catchments are of low priority, except for D82K and F20D, which are used for local water supplies (Table 4.21).

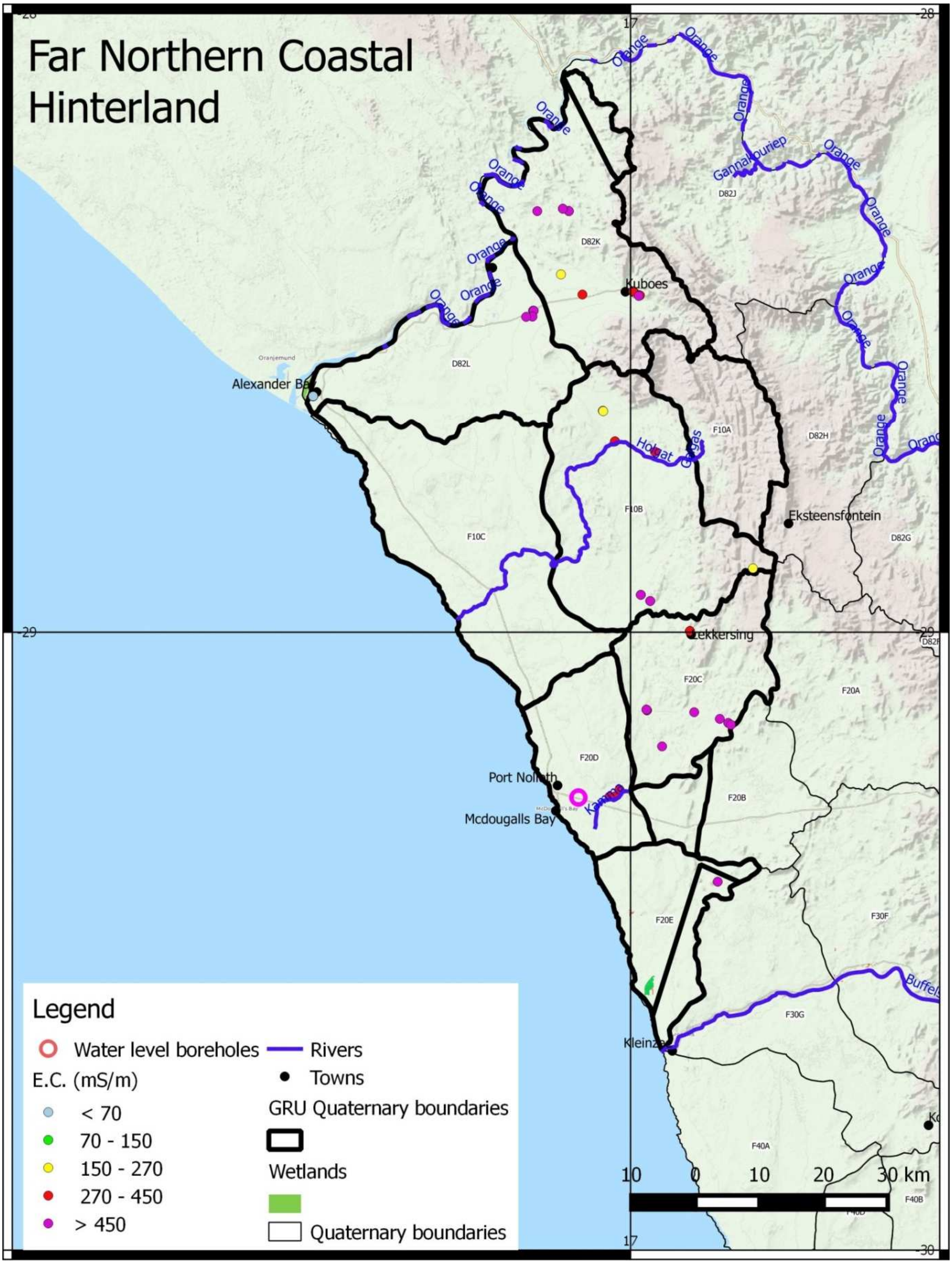


Figure 4.29 **Catchments in Far Northwestern Coastal Hinterland GRU and existing monitoring boreholes**

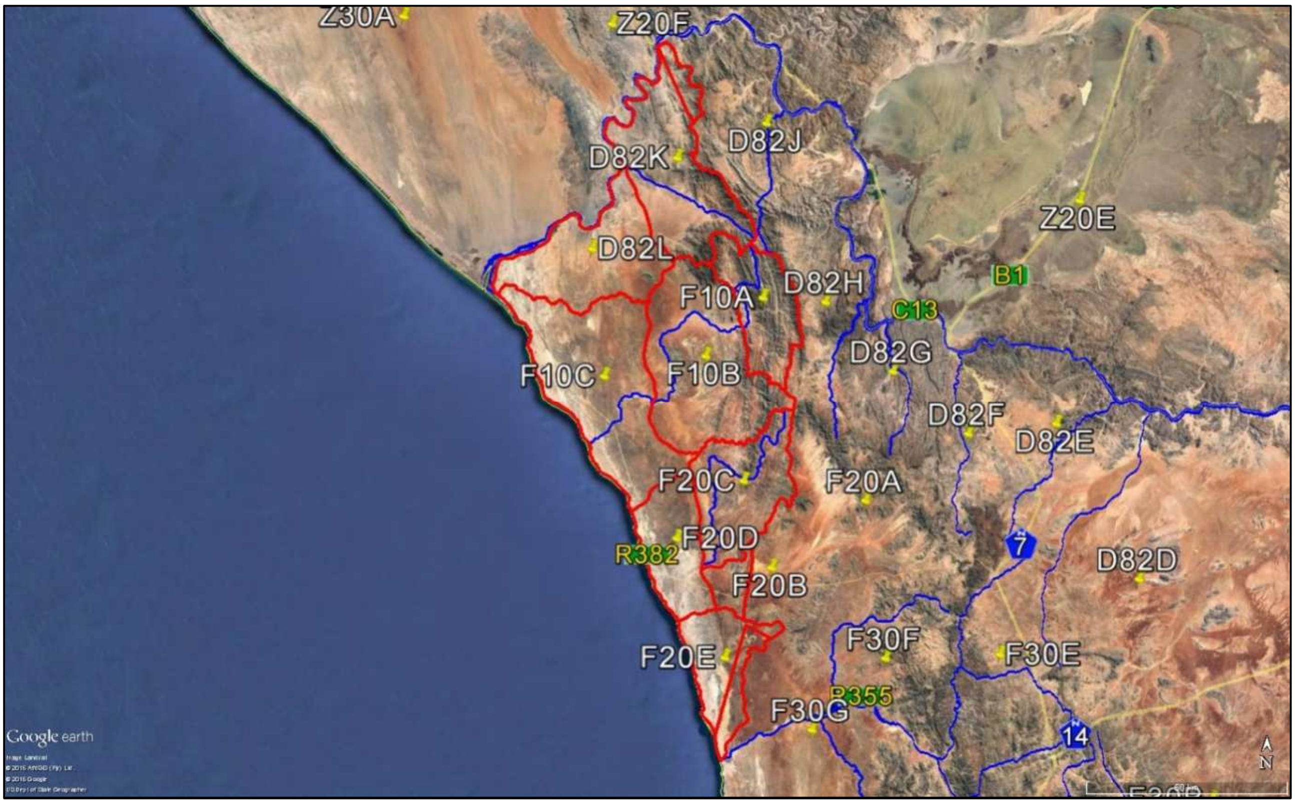


Figure 4.30 Far Northwestern Coastal Hinterland land cover

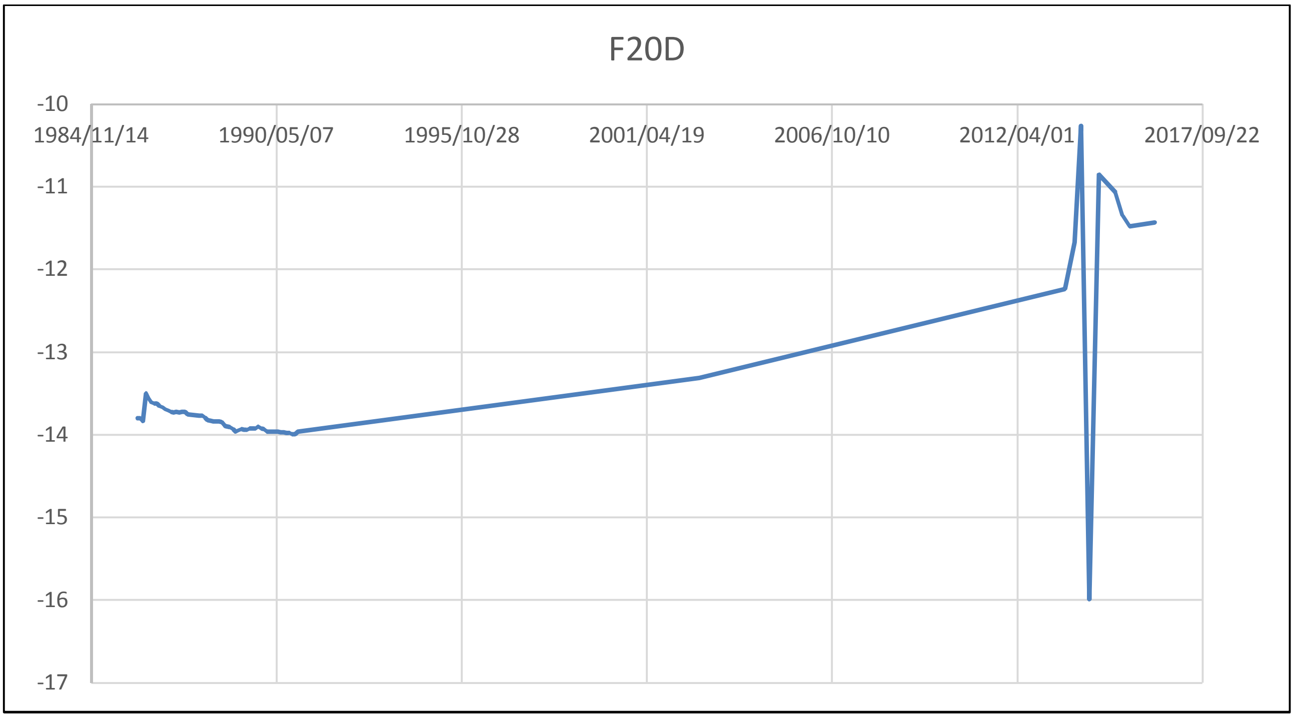


Figure 4.31 Water levels in F20D in mbgl

Table 4-23 Far Northwestern Coastal Hinterland: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D82K	31	100	913	0.04	0.000	0.028	0.000	0.000	0.007	0.065	0.101	0.072	2.63	F
D82L	42	100	748	0.07	0.000	0.023	0.000	0.000	0.006	0.000	0.030	0.006	0.44	D
F10A	64	100	458	0.12	0.000	0.021	0.000	0.000	0.000	0.000	0.021	0.000	0.17	B
F10B	62	100	1085	0.26	0.000	0.049	0.000	0.000	0.000	0.000	0.049	0.000	0.19	B
F10C	53	100	1173	0.19	0.000	0.052	0.000	0.000	0.000	0.000	0.052	0.001	0.27	C
F20B	91	24	122	0.02	0.000	0.005	0.000	0.000	0.000	0.000	0.006	0.001	0.25	C
F20C	80	100	611	0.28	0.000	0.027	0.000	0.000	0.007	0.020	0.055	0.027	0.19	B
F20D	71	100	452	0.15	0.000	0.020	0.000	0.000	0.001	0.409	0.430	0.410	2.78	F
F20E	92	100	432	0.29	0.000	0.019	0.000	0.000	0.000	0.001	0.021	0.001	0.07	B
Total			**5995**	**1.43**	**0.000**	**0.244**	**0.000**	**0.000**	**0.023**	**0.496**	**0.764**	**0.519**		

Table 4-24 Far Northwestern Coastal Hinterland: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D82K	81.85	0	0.010	0.010	**-0.04***			High
D82L	2.64	0	0.008	0.008	0.02			Low
F10A	34.83	0	0.000	0.000	0.06			Low
F10B	34.83	0	0.001	0.001	0.14			Low
F10C	34.83	0	0.001	0.001	0.09			Low
F20B	44.29	0	0.000	0.000	0.01			Low
F20C	81.67	0	0.009	0.009	0.15			Low
F20D	54.96	0	0.001	0.001	**-0.18***	Y		High
F20E	67.55	0	0.000	0.000	0.17			Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Table 4-25 Far Northwestern Coastal Hinterland: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D82K	0	1	2	5	4	0	8	17	42	33	25
D82L	1	0	0	0	4	20	0	0	0	80	20
F10A											
F10B	0	0	3	3	2	0	0	38	38	25	38
F10C											
F20B	0	0	2	4	7	0	0	15	31	54	15
F20C	0	0	0	1	7	0	0	0	13	88	0
F20D	0	0	0	3	0	0	0	0	100	0	0
F20E	0	0	0	0	1	0	0	0	0	100	0

4.3.9 Ghaap Plateau

The GRU consists of eastern Kalahari bushveld adjacent to the Vaal and Orange rivers and their confluence. Surface drainage does not exist due the high permeability of the dolomites (Figures 4.32 and 4.33).

The Ghaap Plateau GRU is underlain by Ghaap Plateau dolomites, which are covered by Kalahari and Tertiary sediments in some places. It is the most significant aquifer in the WMA in terms of recharge, permeability and aquifer storage. Recharge is from 7 - 10 mm/a. The aquifer is of the karts type and mean borehole yields are 1.5 - 2 l/s. Groundwater levels are 15 - 20 mbgl.

Groundwater quality is of Class 1, and nitrates are the only nuisance constituent. Groundwater is of Good quality and mostly of Class 1. The potability of groundwater is almost 100% (Table 4.28).

Griekwastad is dependent on the aquifer. Groundwater use is primarily for water supply, of which Campbell and Griekwastad are the main municipal users. Irrigation also occurs, as does mining at Lime Chem Resources (Table 4.26). The stress index is low due to the high recharge rates of the dolomites. Groundwater levels in D71B show that water levels are stable since 2001 (Figure 4.34).

The GRU is moderately dependent on groundwater for water supply, except for D71B, which is heavily dependent. Due the dolomitic nature of the terrain, the catchments are considered of intermediate priority in spite of the low stress index (Table 4.27).

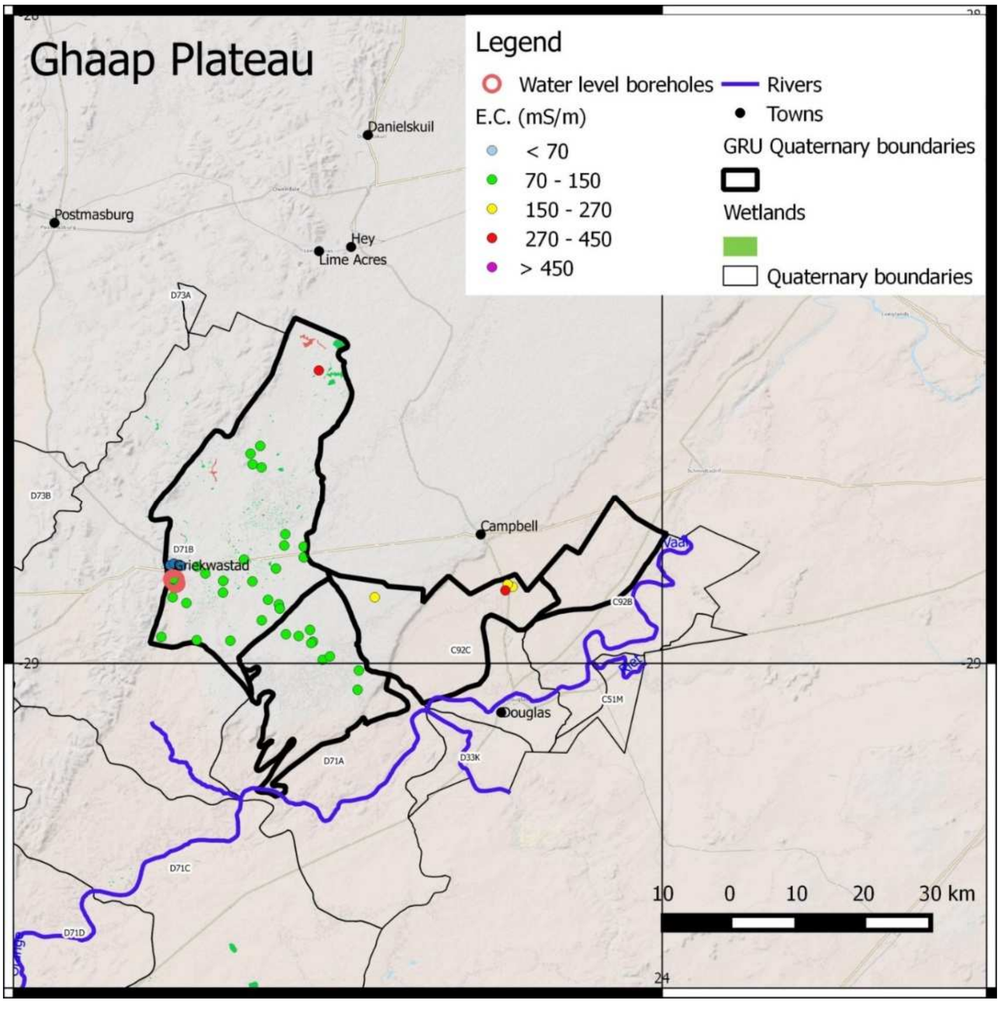


Figure 4.32 Catchments in Ghaap Plateau GRU and existing monitoring boreholes

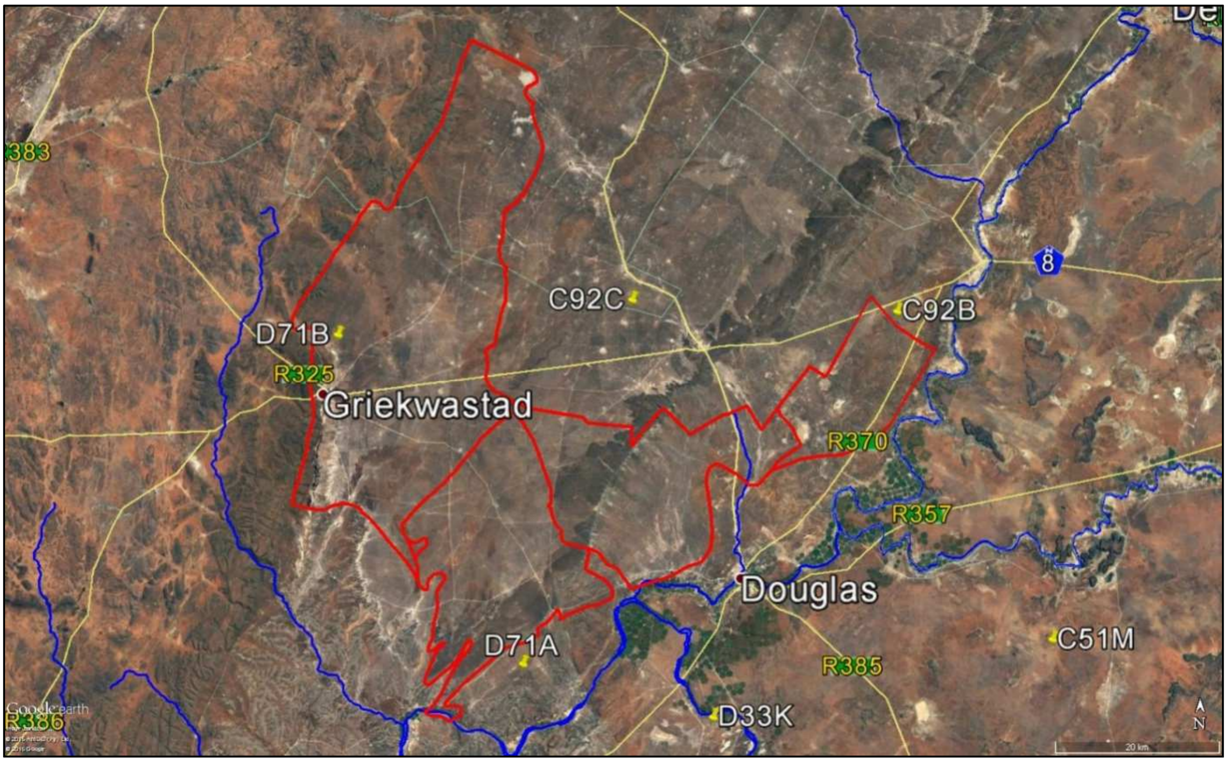


Figure 4.33 Ghaap Plateau land cover

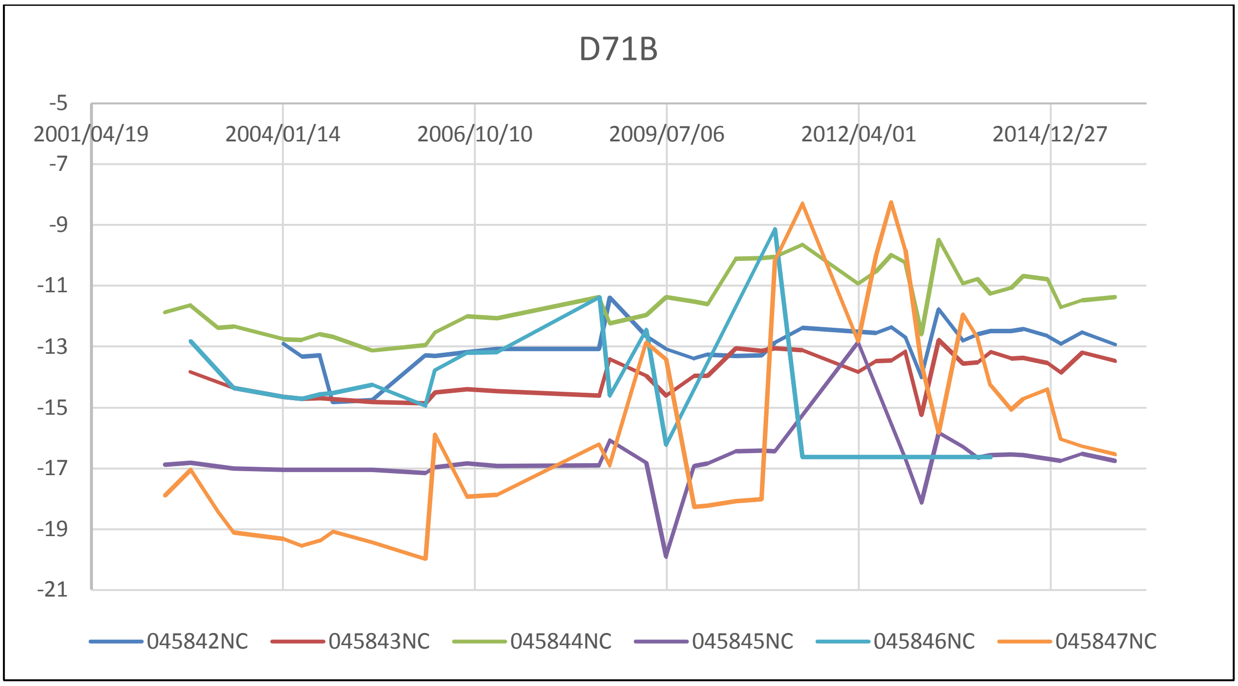


Figure 4.34 Water levels in D71B in mbgl

Table 4-26 Ghaap Plateau: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
C92B	331	30	191	1.45	0.042	0.028	0.000	0.000	0.024	0.000	0.094	0.024	0.06	B
C92C	326	66	410	3.93	0.291	0.030	0.001	0.000	0.075	0.473	0.870	0.548	0.22	C
D71A	283	36	436	3.01	0.031	0.034		0.000	0.007	0.001	0.072	0.008	0.02	A
D71B	315	38	1000	7.41	0.058	0.064	0.092	0.000	0.023	0.500	0.737	0.523	0.10	B
Total			**2037**	**15.80**	**0.422**	**0.156**	**0.093**	**0.000**	**0.130**	**0.974**	**1.774**	**1.104**		

Table 4-27 Ghaap Plateau: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
C92B	51.73	0	0.032	0.032	0.880			Intermediate
C92C	6.18	0	0.095	0.095	1.974			Intermediate
D71A	61.22	0	0.008	0.008	1.909		Y	Intermediate
D71B	92.62	0	0.030	0.030	4.331			Intermediate

Table 4-28 Ghaap Plateau: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
C92B											
C92C	15	74	13	1	0	15	72	13	1	0	99
D71A	0	11	0	0	0	0	100	0	0	0	100
D71B	16	43	1	1	0	26	70	2	2	0	98

4.3.10 Karoo Sandstone and Shale West

The GRU consists of Karoo rangeland drained by the Renoster, the Vis, and the Sak rivers. In the east, the GRU extends to the Karoo escarpment (Figures 4.35 and 4.36).

The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Recharge increases from 1 - 3 mm/a from north to south, being highest in the Sutherland vicinity. The aquifer is of the fractured type and mean borehole yields are 1 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 15 mbgl.

Groundwater quality is of Class 1 - 2, however arsenic and molybdenum can be encountered. The potability of groundwater is over 90% (Table 4.31).

The aquifer is a sole source aquifer and Fraserburg and Loxton rely on groundwater. Groundwater use is primarily for irrigation, however, water supply to Fraserburg and Loxton are a significant component of the water use (Table 4.29). The stress index is variable but is high in D52C due to irrigation. Groundwater levels in D55D and D55E indicate dropping water levels in the vicinity of Loxton and Fraserburg, despite only low to moderate stress indices in those catchments, suggesting that localised dewatering is occurring due to local aquifers not being connected hydraulically to the remainder of the catchment (Figure 4.37 and 3.38).

The GRU is highly dependent on groundwater for water supply, consequently, catchments used for water supply are considered of high priority if they exhibit dropping water levels. D52C warrants being considered of intermediate priority due to a high stress index resulting from irrigation (Table 4.30).

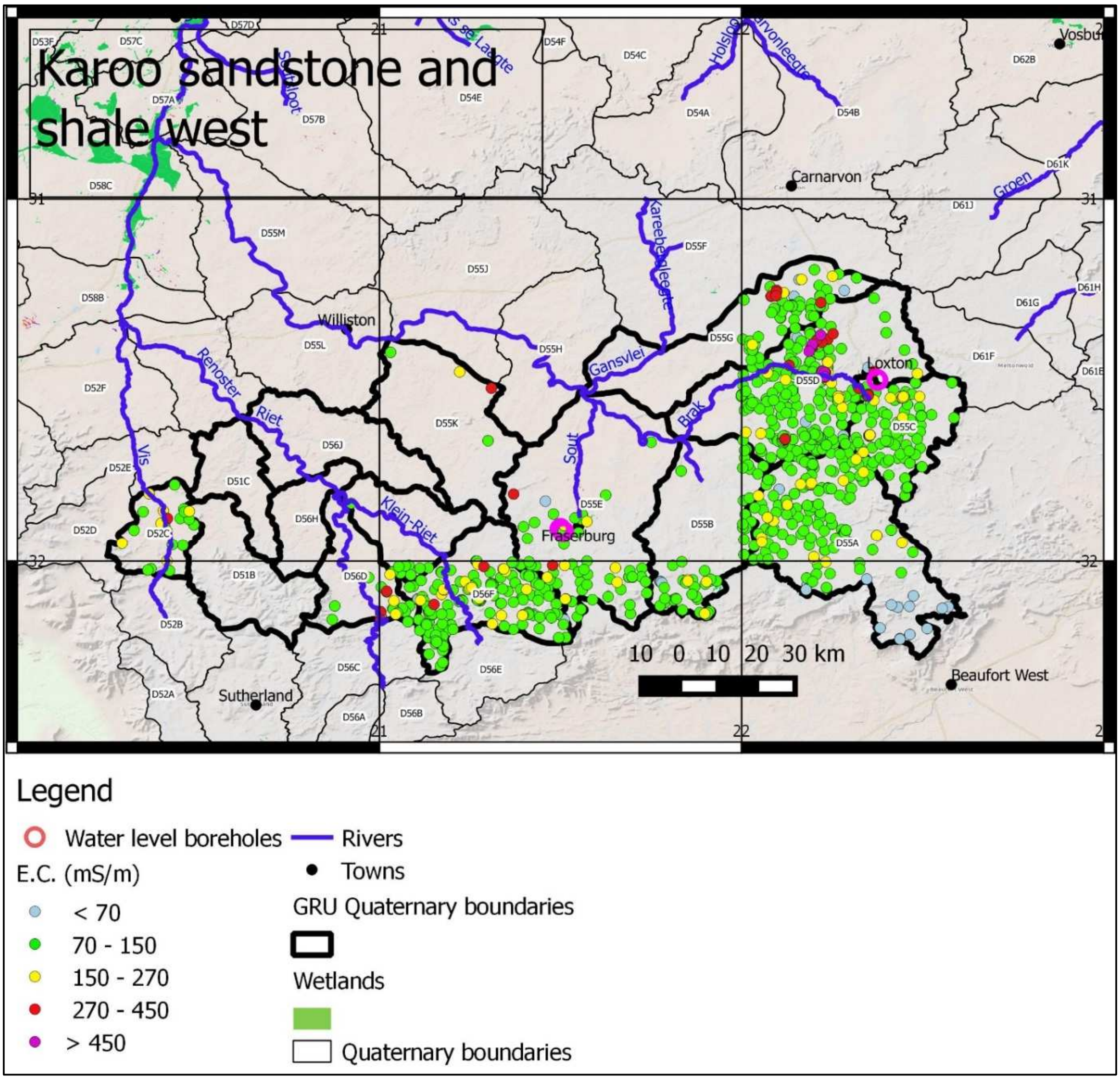


Figure 4.35 Catchments in the Karoo Sandstone and Shale West GRU and existing monitoring boreholes

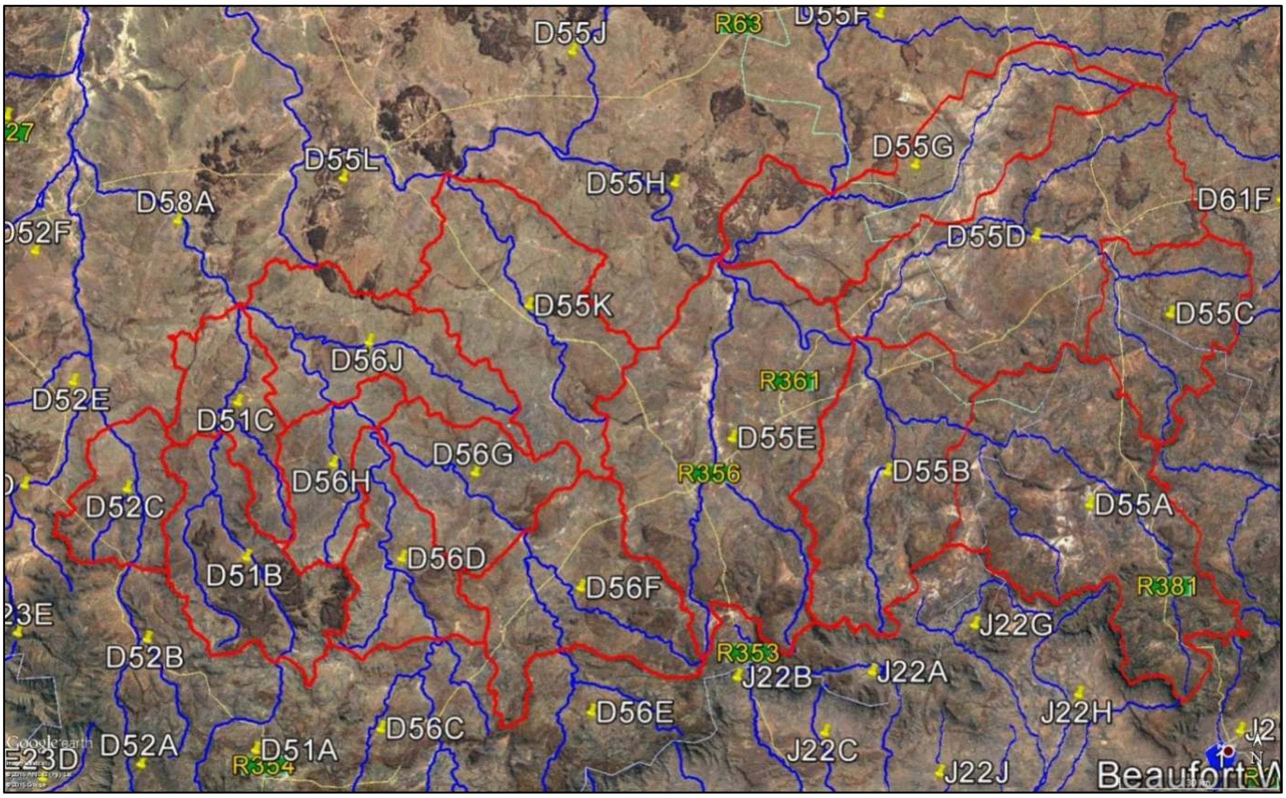


Figure 4.36 Karoo Sandstone and Shale West land cover

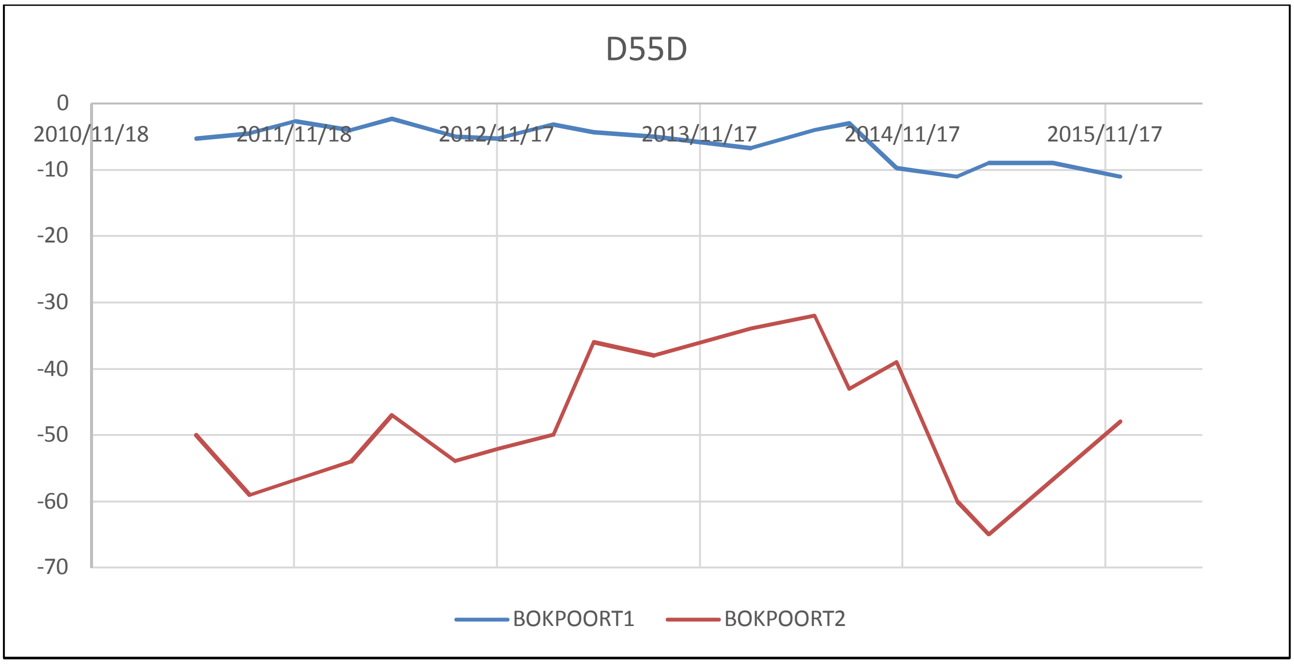


Figure 4.37 Water levels in D55D in mbgl

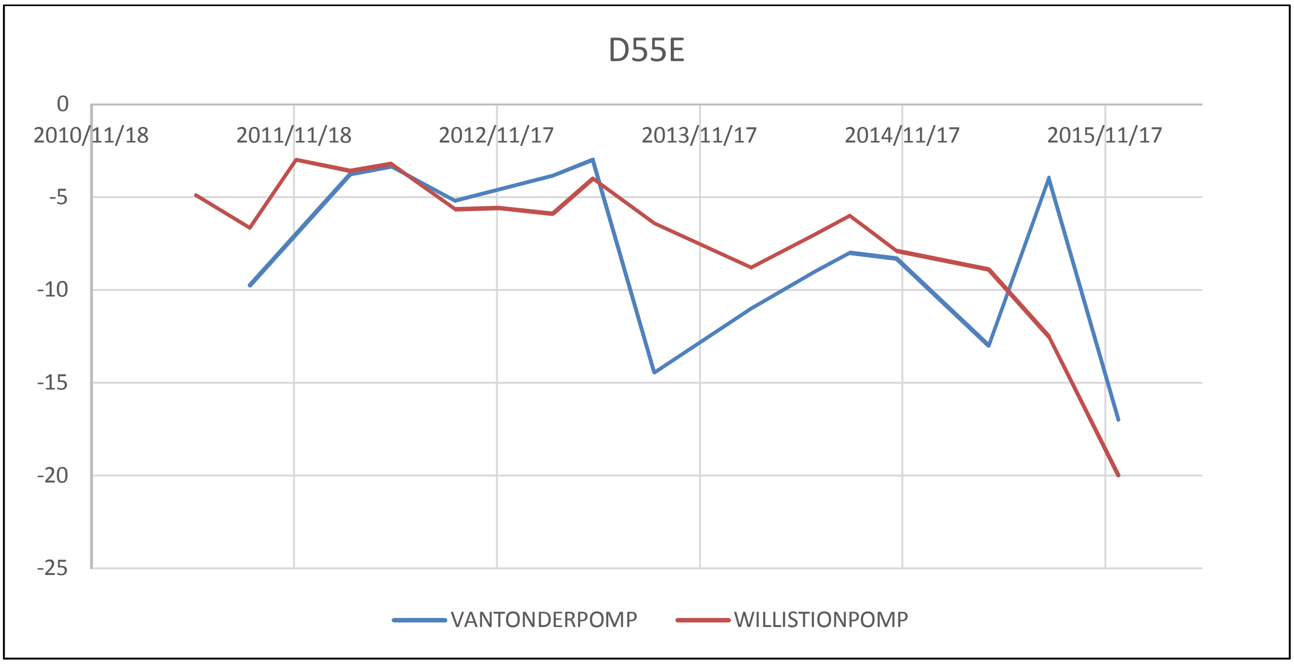


Figure 4.38 Water levels in D55E in mbgl

Table 4-29 Karoo Sandstone and Shale West: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D51B	240	100	873	2.54	0.443	0.031	0.000	0.000	0.006	0.000	0.480	0.006	0.19	B
D51C	176	100	522	0.82	0.000	0.008	0.000	0.000	0.004	0.000	0.012	0.004	0.01	A
D52C	193	100	465	0.63	0.447	0.017	0.000	0.000	0.003	0.000	0.467	0.003	0.74	E
D55A	221	100	1872	4.97	0.046	0.020	0.000	0.000	0.039	0.001	0.106	0.039	0.02	A
D55B	187	100	1259	3.01	0.203	0.069	0.000	0.000	0.009	0.000	0.281	0.009	0.09	B
D55C	217	100	760	2.96	0.167	0.027	0.000	0.000	0.012	0.003	0.207	0.014	0.07	B
D55D	191	100	1889	4.51	0.677	0.115	0.000	0.000	0.024	0.445	1.262	0.469	0.28	C
D55E	173	100	2240	3.16	0.021	0.123	0.000	0.000	0.022	0.192	0.358	0.214	0.11	B
D55G	171	100	1293	1.93	0.000	0.079	0.000	0.000	0.012	0.000	0.091	0.013	0.05	A
D55K	158	100	1247	1.40	0.055	0.031	0.000	0.000	0.009	0.000	0.095	0.009	0.07	B
D56D	189	100	621	0.93	0.050	0.020	0.000	0.000	0.004	0.000	0.074	0.004	0.08	B
D56F	191	100	1038	1.61	0.218	0.057	0.000	0.000	0.007	0.000	0.282	0.007	0.18	B
D56G	176	100	651	0.91	0.014	0.036	0.000	0.000	0.004	0.000	0.054	0.005	0.06	B
D56H	174	100	447	0.47	0.005	0.010	0.000	0.000	0.003	0.000	0.018	0.003	0.04	A
D56J	167	100	931	1.24	0.050	0.030	0.000	0.000	0.006	0.000	0.086	0.007	0.07	B
Total			**16109**	**31.09**	**2.395**	**0.671**	**0.000**	**0.000**	**0.164**	**0.642**	**3.872**	**0.807**		

Table 4-30 Karoo sandstone and Shale West: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D51B	92.14	0	0.008	0.008	1.335			Low
D51C	92.02	0	0.005	0.005	0.523			Low
D52C	92.1	0	0.004	0.004	0.103			Intermediate
D55A	94.33	0	0.050	0.050	3.154			Low
D55B	91.73	0	0.011	0.011	1.770			Low
D55C	92.09	0	0.015	0.015	1.788			Low
D55D	96.33	0	0.031	0.031	2.107	N	5	High
D55E	98.78	0	0.029	0.029	1.820	N	15	High
D55G	88.27	0	0.016	0.016	1.195			Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D55K	92.15	0	0.011	0.011	0.847			Low
D56D	92.15	0	0.005	0.005	0.556			Low
D56F	92.15	0	0.009	0.009	0.861			Low
D56G	92.15	0	0.006	0.006	0.555			Low
D56H	92.15	0	0.004	0.004	0.296			Low
D56J	92.15	0	0.008	0.008	0.749			Low

Table 4-31 Karoo sandstone and Shale West: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D51B	0	0	1	0	0	0	0	100	0	0	100
D51C											
D52C	0	15	6	1	0	0	68	27	5	0	95
D55A	19	125	18	0	0	12	77	11	0	0	100
D55B	4	51	5	0	0	7	85	8	0	0	100
D55C	0	88	22	2	0	0	79	20	2	0	98
D55D	10	168	25	11	8	5	76	11	5	4	91
D55E	1	48	7	2	0	2	83	12	3	0	97
D55G	4	47	6	5	0	6	76	10	8	0	92
D55K	0	2	1	1	0	0	50	25	25	0	75
D56D	0	19	5	2	0	0	73	19	8	0	92
D56F	7	133	18	2	0	4	83	11	1	0	99
D56G	0	9	0	0	0	0	100	0	0	0	100
D56H											
D56J											

4.3.11 Karoo Sandstone and shale East

The GRU consists of Karoo rangeland drained by tributaries of the Renoster and the Brak rivers. The GRU extends southward to the Karoo Escarpment, which forms the southeastern margin of the WMA (Figures 4.39 and 4.40).

The Karoo sandstones and shales of the Beaufort Group, which underlie the GRU, overlie the Ecca Group. Recharge increases from 3 mm/a near Loxton, to nearly 12 mm/a around De Aar. The aquifer is of the fractured type and mean borehole yields are 1.5 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 15 mbgl.

Groundwater quality is Good to Marginal, of Class 1 - 2, with the marginal groundwater found in the South East between Richmond and De Aar. Arsenic and Molybdenum can be encountered. The potability of groundwater is over 90% (Table 4.34), however some boreholes exhibit unexpectedly high salinity, which could be indicative of upwelling deeper groundwater. Since the GRU forms a high lying recharge area with no potential for groundwater flow from upgradient, it has higher recharge than the Karoo further west, and the rocks are of a continental environment not of marine origin, high salinity would not be expected, as is the case in over 90% of boreholes. The pockets of higher salinity could indicate areas of upwelling groundwater.

The aquifer is a sole source of supply for De Aar, Richmond, and Victoria West. Groundwater use is primarily for irrigation, however, water supply to De Aar, Richmond and Victoria West are a significant component of the water use (Table 4.32). The stress index is low to moderate. Groundwater levels in D61A near Richmond indicate dropping water levels despite only a moderate stress index, suggesting that localised dewatering is occurring due to local aquifers not being hydraulically connected to the remainder of the catchment (Figure 4.41). Water levels in D61E and in the De Aar vicinity in D62C and D62D remain stable over the long term despite periods of dropping water levels during dry periods (Figures 4.42 to 4.47).

The GRU is highly dependent on groundwater for water supply, consequently, catchments used for water supply are considered of high priority if they exhibit dropping water levels (Table 4.33).

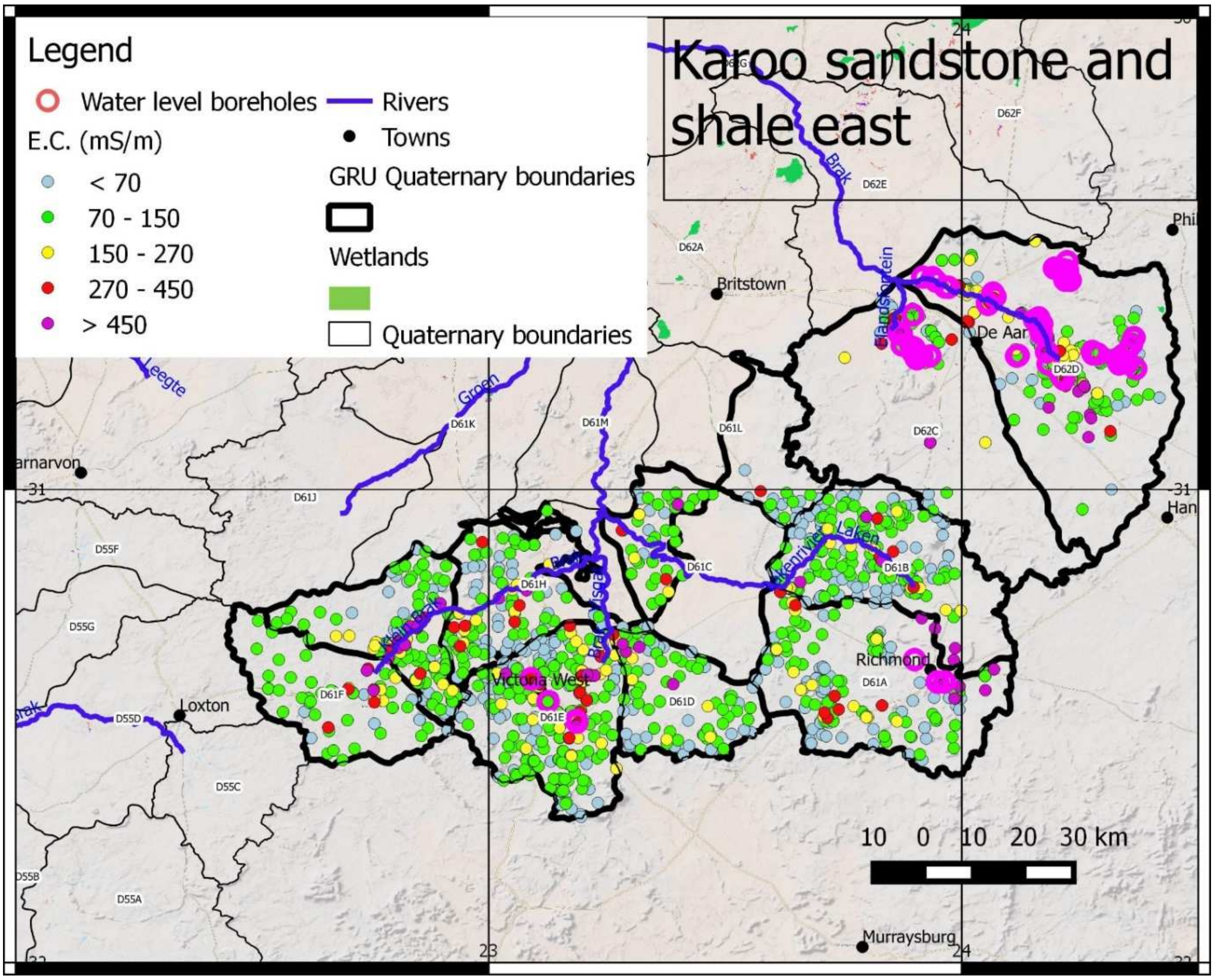


Figure 4.39 Catchments in the Karoo Sandstone and Shale East GRU and existing monitoring boreholes

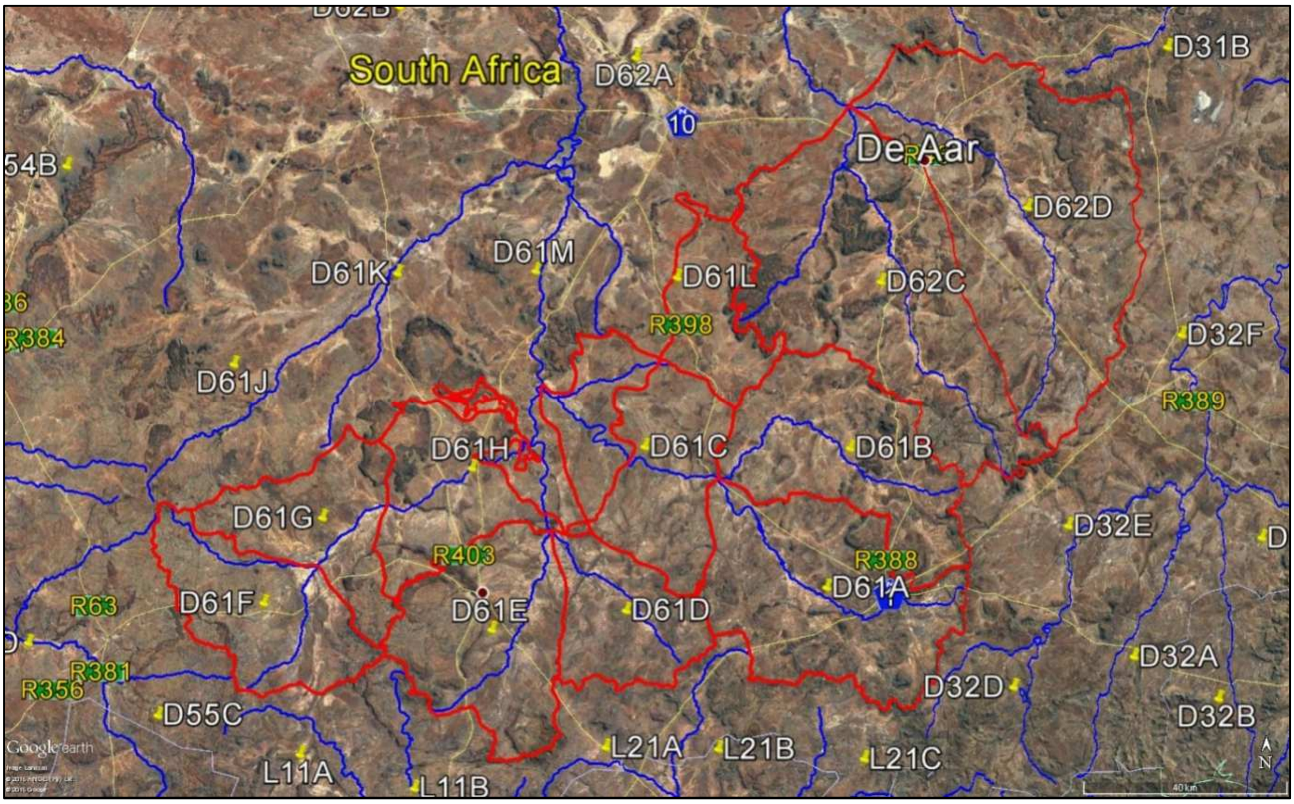


Figure 4.40 Karoo Sandstone and Shale East land cover

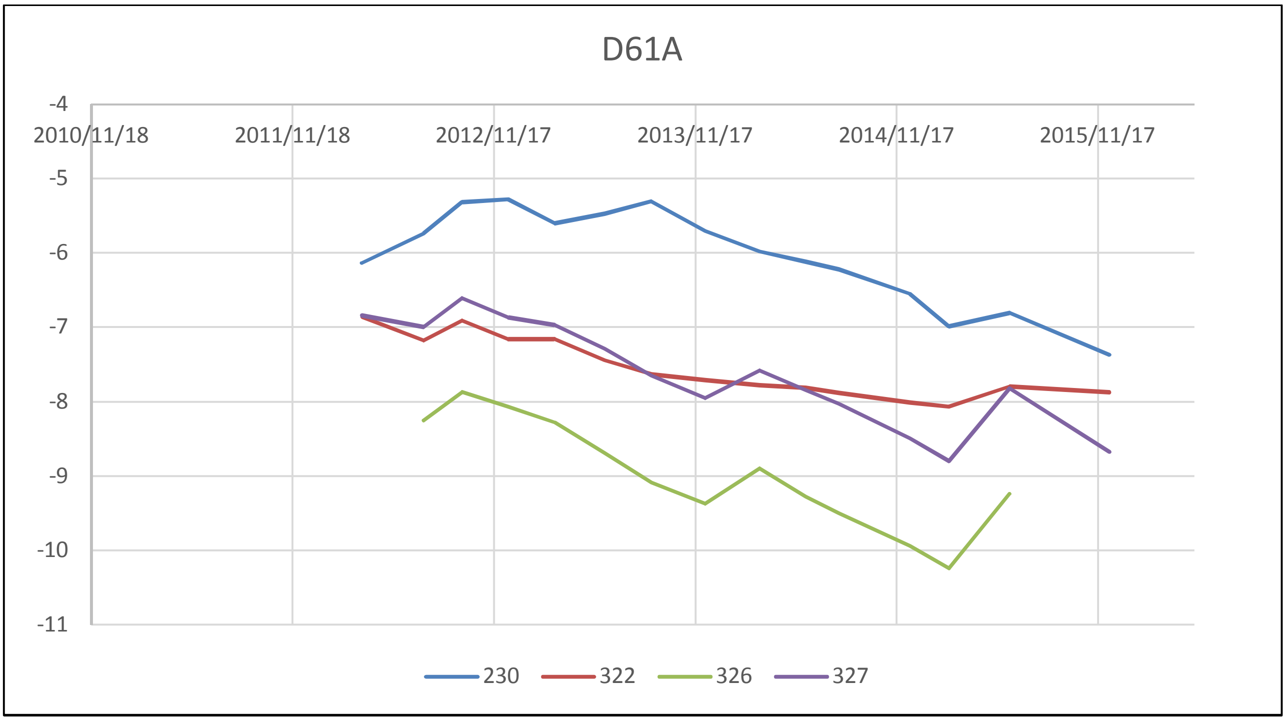


Figure 4.41 Water levels in D61A in mbgl

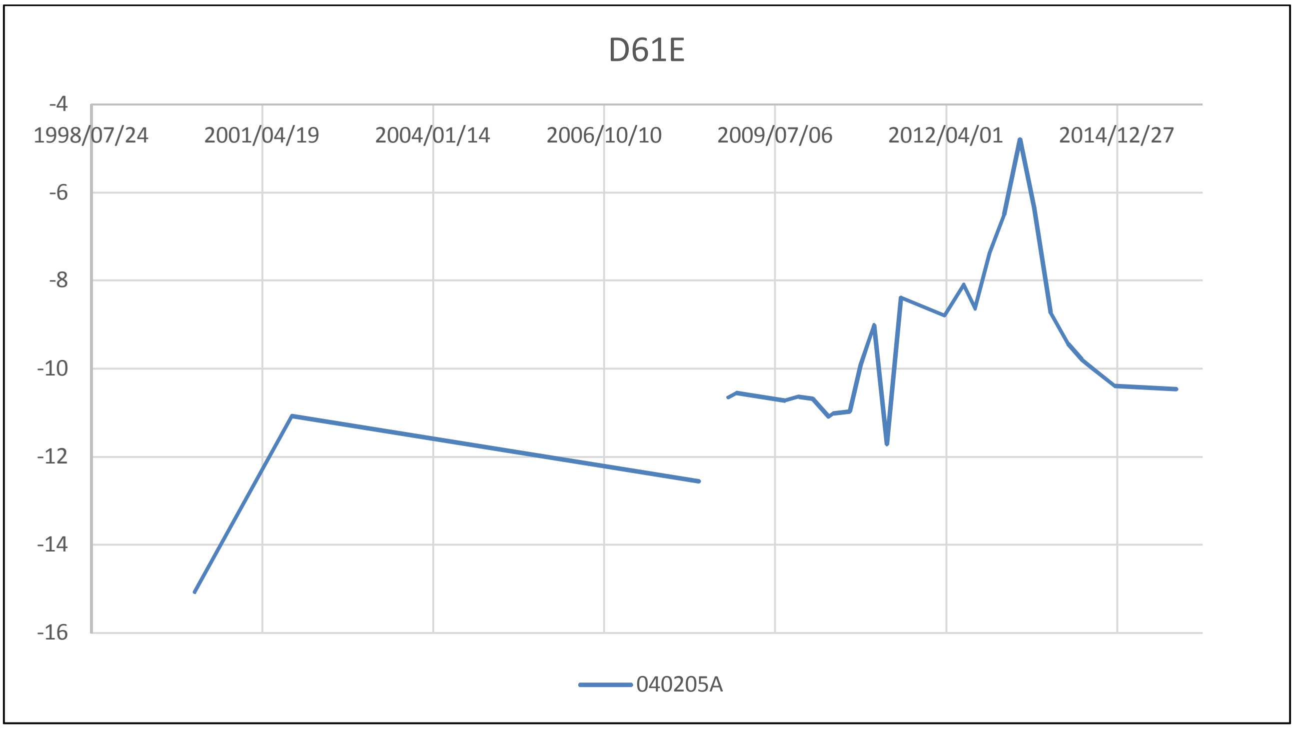


Figure 4.42 Water levels in D61E in mbgl

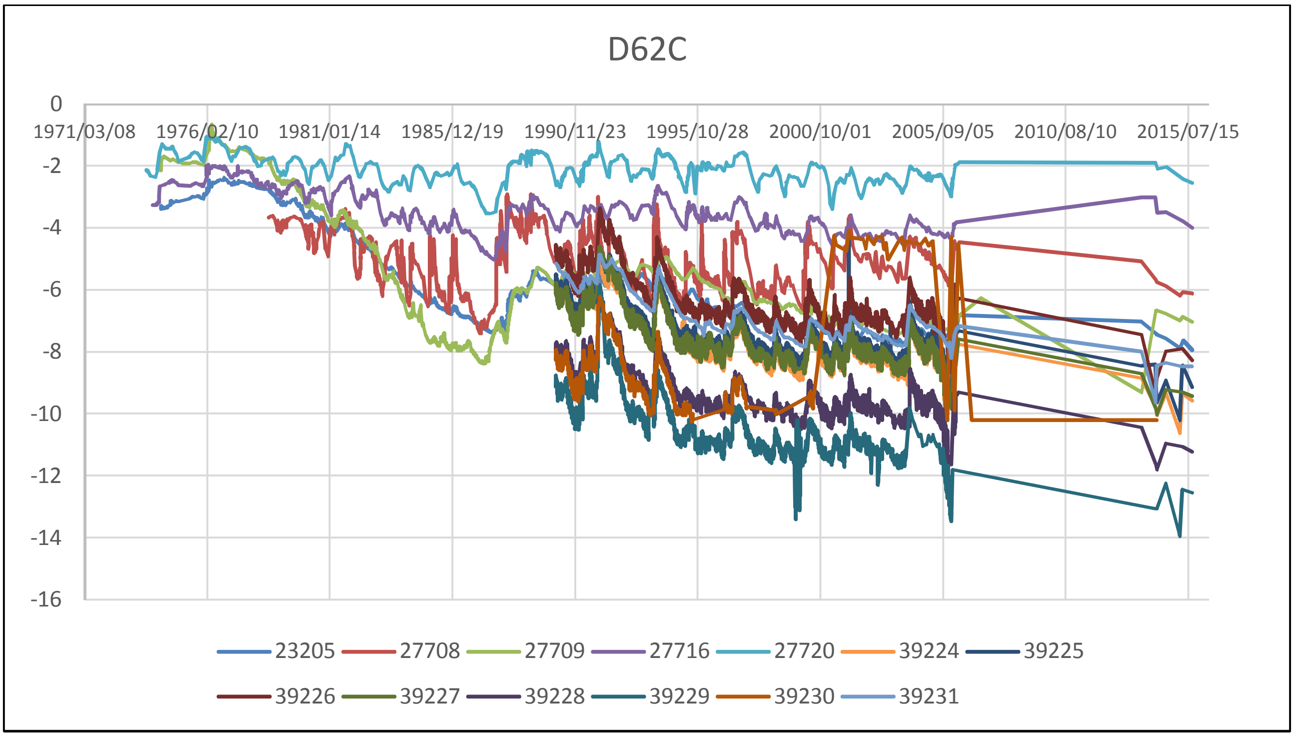


Figure 4.43 Water levels in D62C in mbgl

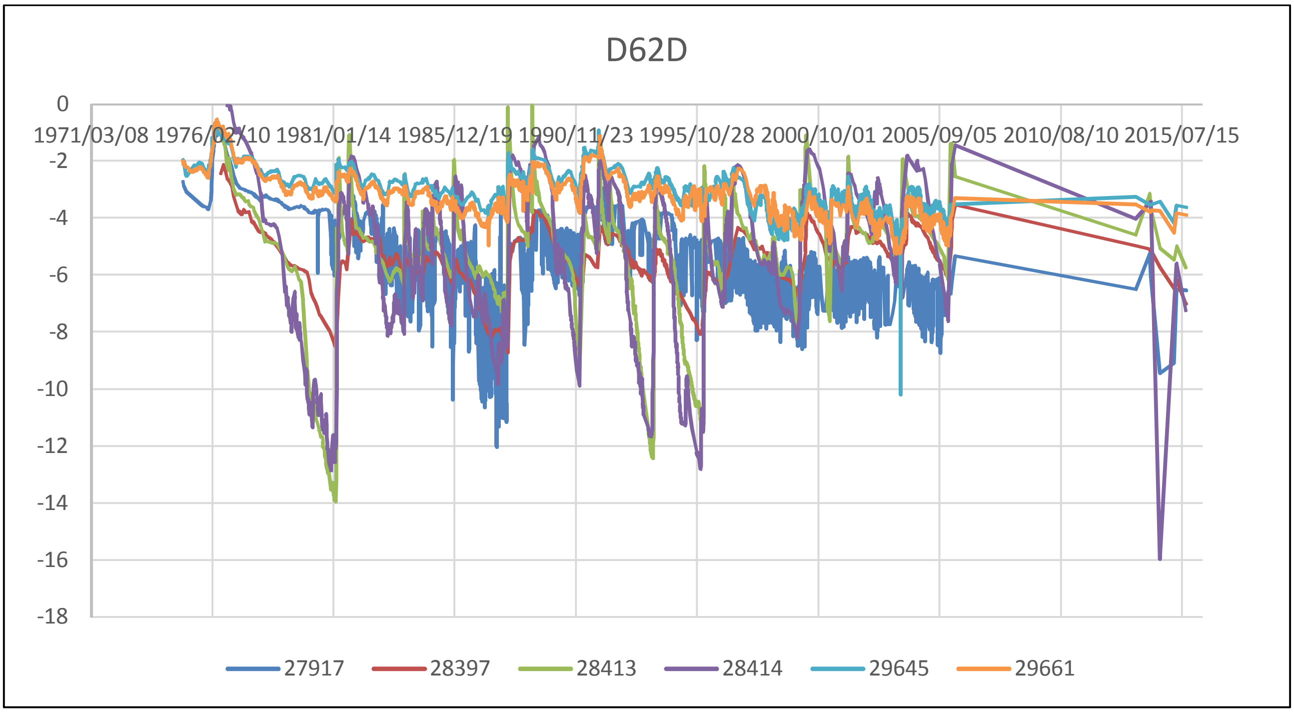


Figure 4.44 Water levels in D62D in mbgl

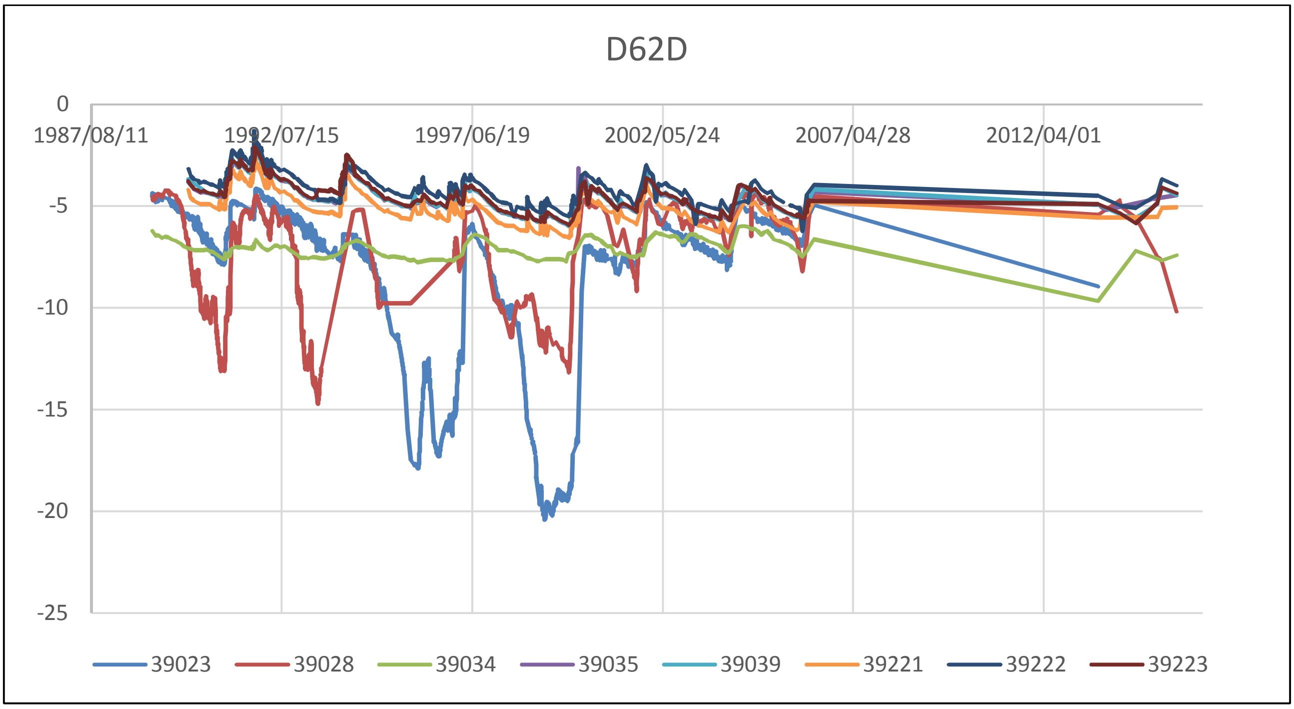


Figure 4.45 Water levels in D62D in mbgl

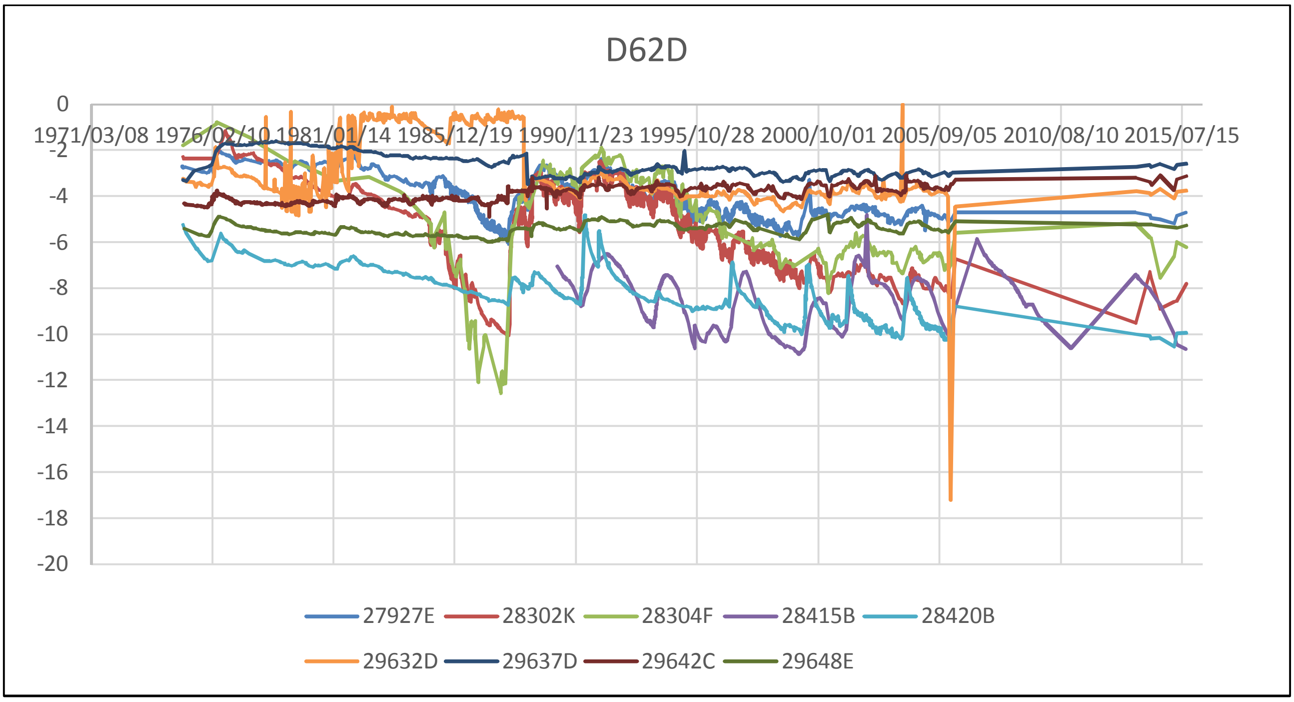


Figure 4.46 Water levels in D62D in mbgl

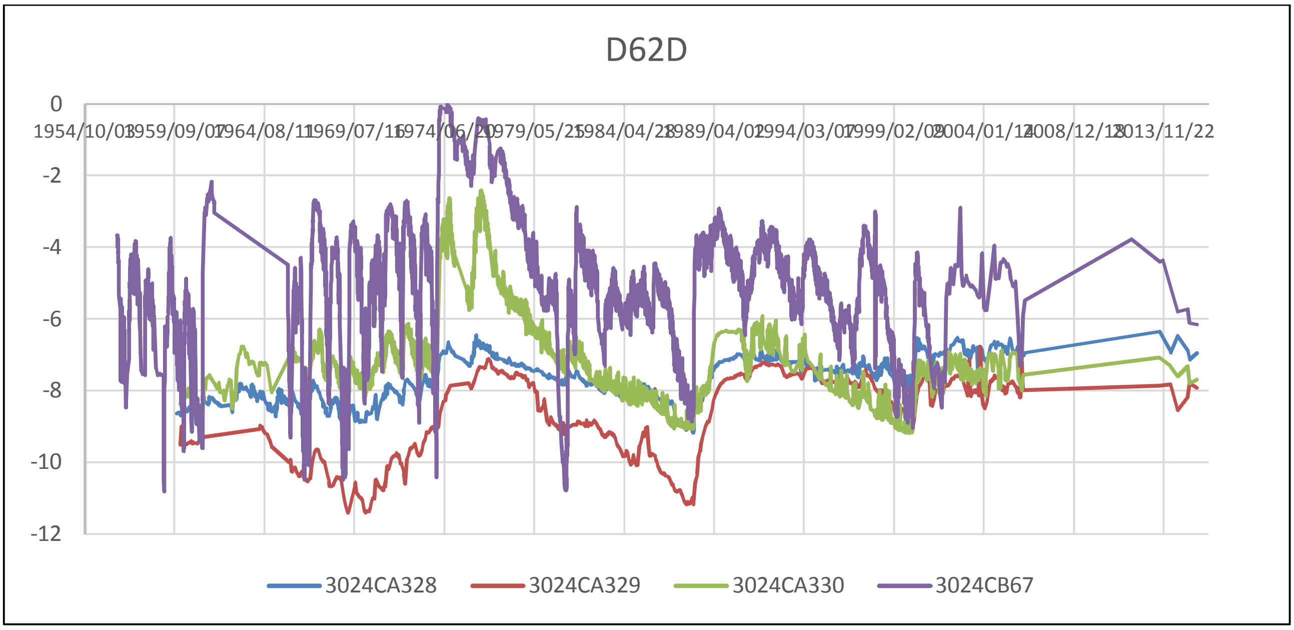


Figure 4.47 Water levels in D62D in mbgl

Table 4-32 Karoo Sandstone and Shale East: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D61A	275	100	1464	8.46	1.519	0.080	0.000	0.000	0.032	0.564	2.195	0.596	0.26	C
D61B	272	100	1196	5.81	0.487	0.069	0.000	0.000	0.015	0.002	0.573	0.017	0.10	B
D61C	247	100	1169	6.96	0.306	0.078	0.000	0.000	0.013	0.000	0.397	0.014	0.06	B
D61D	242	100	650	2.66	0.461	0.045	0.000	0.000	0.007	0.000	0.514	0.008	0.19	B
D61E	231	100	1090	5.99	0.613	0.079	0.000	0.000	0.028	0.722	1.443	0.750	0.24	C
D61F	204	100	873	2.79	0.163	0.064	0.000	0.000	0.010	0.000	0.237	0.010	0.08	B
D61G	216	100	743	2.88	0.239	0.054	0.000	0.000	0.009	0.000	0.302	0.009	0.10	B
D61H	231	72	785	3.83	0.084	0.057			0.009	0.000	0.151	0.009	0.04	A
D61L	270	50	511	3.76	0.020	0.033			0.006	0.000	0.059	0.006	0.02	A
D62C	278	100	2126	15.81	0.211	0.174	0.000	0.000	0.037	0.067	0.488	0.103	0.03	A
D62D	299	100	2397	28.50	1.269	0.136	0.000	0.025	0.070	2.798	4.299	2.868	0.15	B
Total			**13003**	**87.46**	**5.373**	**0.869**	**0.000**	**0.025**	**0.237**	**4.154**	**10.658**	**4.390**		

Table 4-33 Karoo Sandstone and Shale East: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D61A	89.11	0	0.041	0.041	4.069	N	1	High
D61B	85.45	0	0.019	0.019	3.404			Low
D61C	86.66	0	0.017	0.017	4.264			Low
D61D	86.42	0	0.010	0.010	1.392			Low
D61E	96.36	0	0.036	0.036	2.949	Y		High
D61F	86.42	0	0.013	0.013	1.659			Low
D61G	86.42	0	0.011	0.011	1.677			Low
D61H	86.42	0	0.012	0.012	2.388			Low
D61L	90.36	0	0.008	0.008	2.405			Low
D62C	96.04	0	0.048	0.048	9.951	Y	2	High
D62D	98.97	0	0.091	0.091	15.719	Y	2	High

Table 4-34 Karoo Sandstone and Shale East: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D61A	59	66	13	7	7	39	43	9	5	5	91
D61B	74	86	13	4	6	40	47	7	2	3	95
D61C	56	84	8	3	2	37	55	5	2	1	97
D61D	30	46	6	1	4	34	53	7	1	5	94
D61E	101	144	38	13	4	34	48	13	4	1	94
D61F	10	38	5	5	2	17	63	8	8	3	88
D61G	41	90	18	5	8	25	56	11	3	5	92
D61H	57	59	11	6	2	42	44	8	4	1	94
D61L	13	7	0	1	0	62	33	0	5	0	95
D62C	15	46	28	12	3	14	44	27	12	3	86
D62D	31	138	45	20	19	12	55	18	8	8	85

4.3.12 Namaqualand East

The GRU consists of the hilly uplands of Namaqualand that divides drainage to the Orange from catchments that drain to the Atlantic Ocean. Most of the GRU drains to the sea via the Buffels River (Figures 4.48 and 4.49).

The Namaqualand East GRU is underlain by rocks of the Nama and Vanrhynsdorp Groups. Recharge is from less than 1 mm to 2 mm. The aquifer is of the fractured and weathered type and mean borehole yields are 0.5 - 2 l/s. Groundwater levels are from 12 - 30 mbgl. This GRU was separated from the rest of Namaqualand Groundwater Region due to a higher water levels and recharge than the rest of Namaqualand and a better water quality class, which is of Class 2 - 3, for domestic purposes.

Groundwater is of very variable quality, however, approximately 50% of boreholes are potable (Table 4.37). Arsenic is present in groundwater.

Springbok, Kammassies and Paulshoek utilise groundwater, and groundwater use is primarily for water supply for all communities between Kamieskoon and Springbok (Table 4.35). The stress index is high in F30D due to abstraction for Springbok. Groundwater level data is of too short a duration to observe water level trends (Figure 4.50). The groundwater stress index is high in D82D; however, it is uncertain if this can be attributed to too low a recharge estimate for the Quaternary, since much of the remainder of the catchment lies in the drier Bushmanland West GRU that has lower recharge.

The GRU is only moderately dependent on groundwater for water supply, consequently, only catchments where water supply result in a high stress index are considered of high priority (Table 4.36).

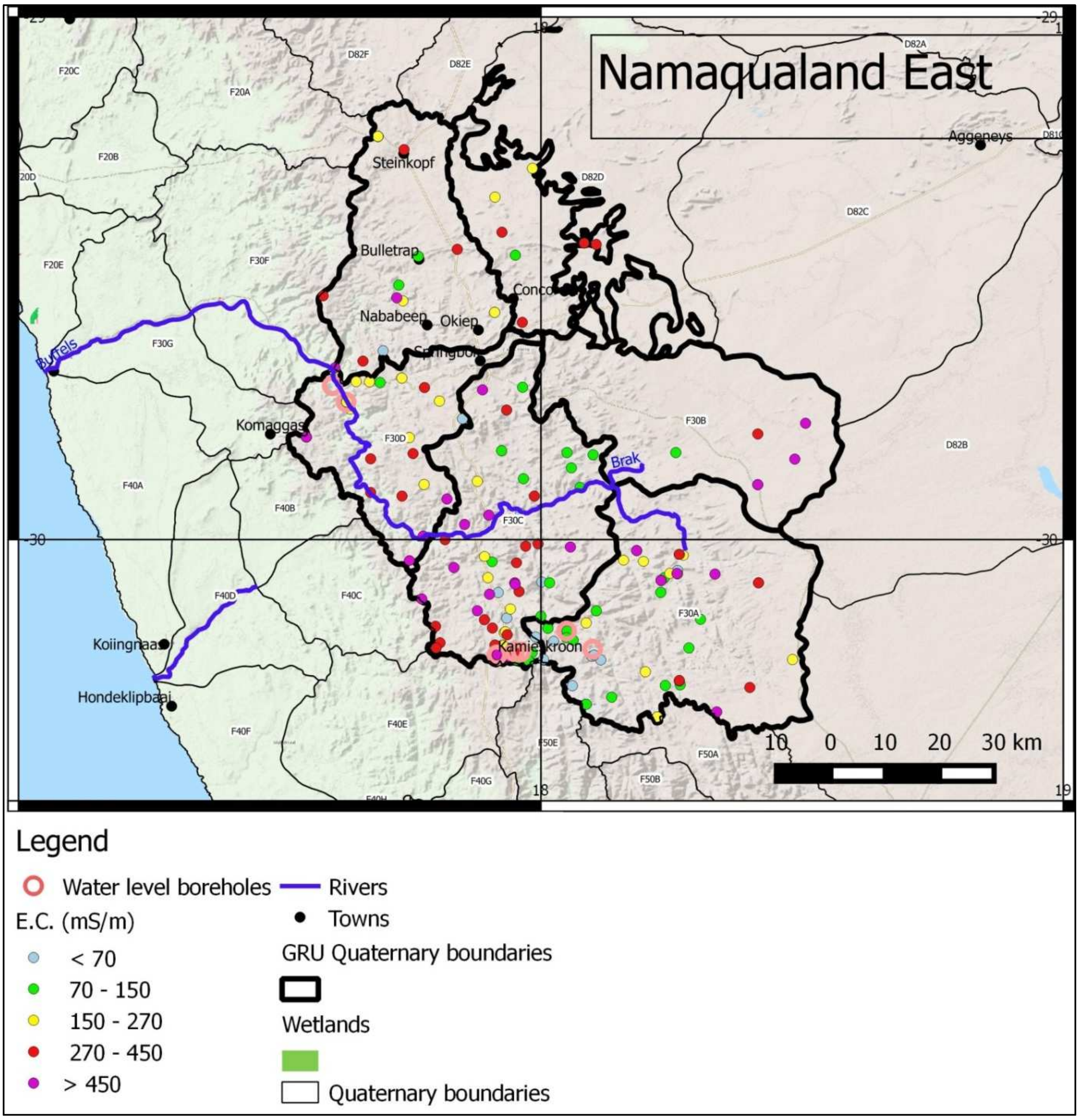


Figure 4.48 Catchments in Namaqualand East GRU and existing monitoring boreholes

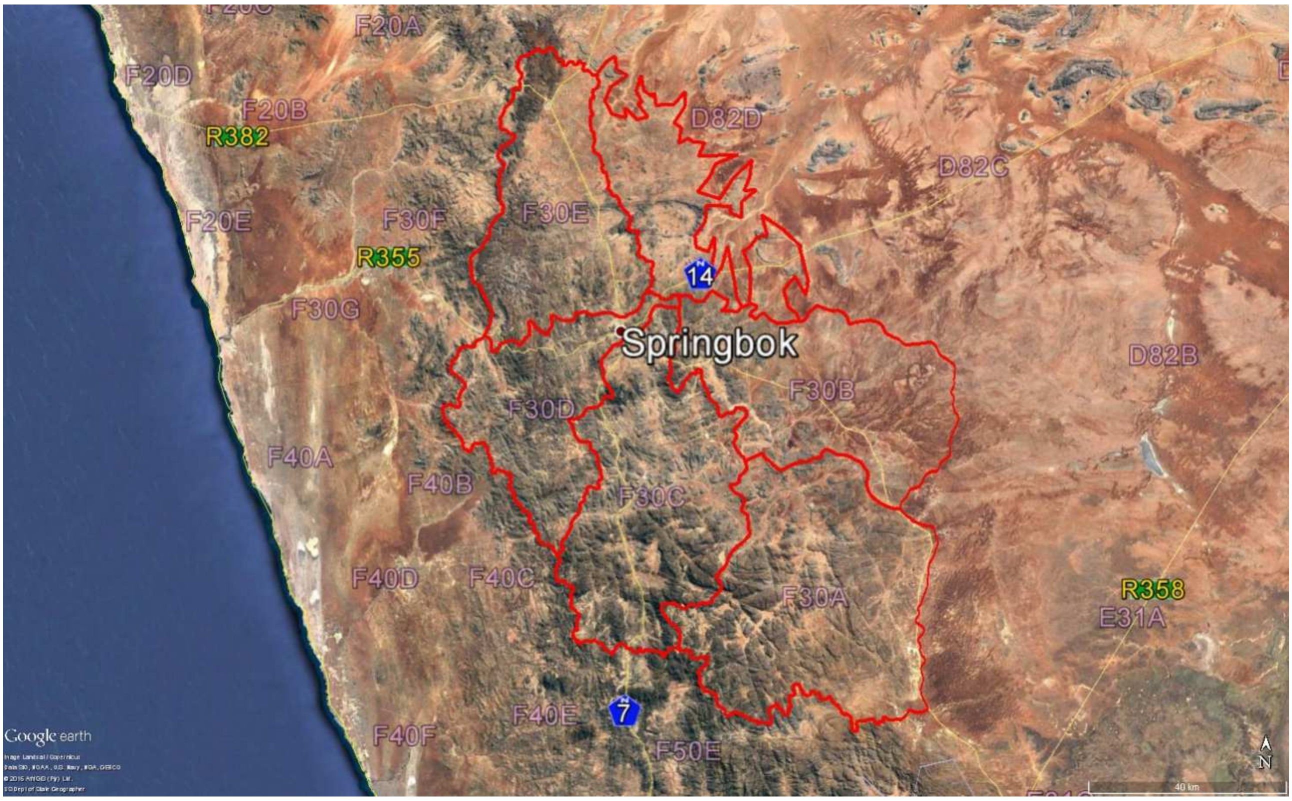


Figure 4.49 Namaqualand East land cover

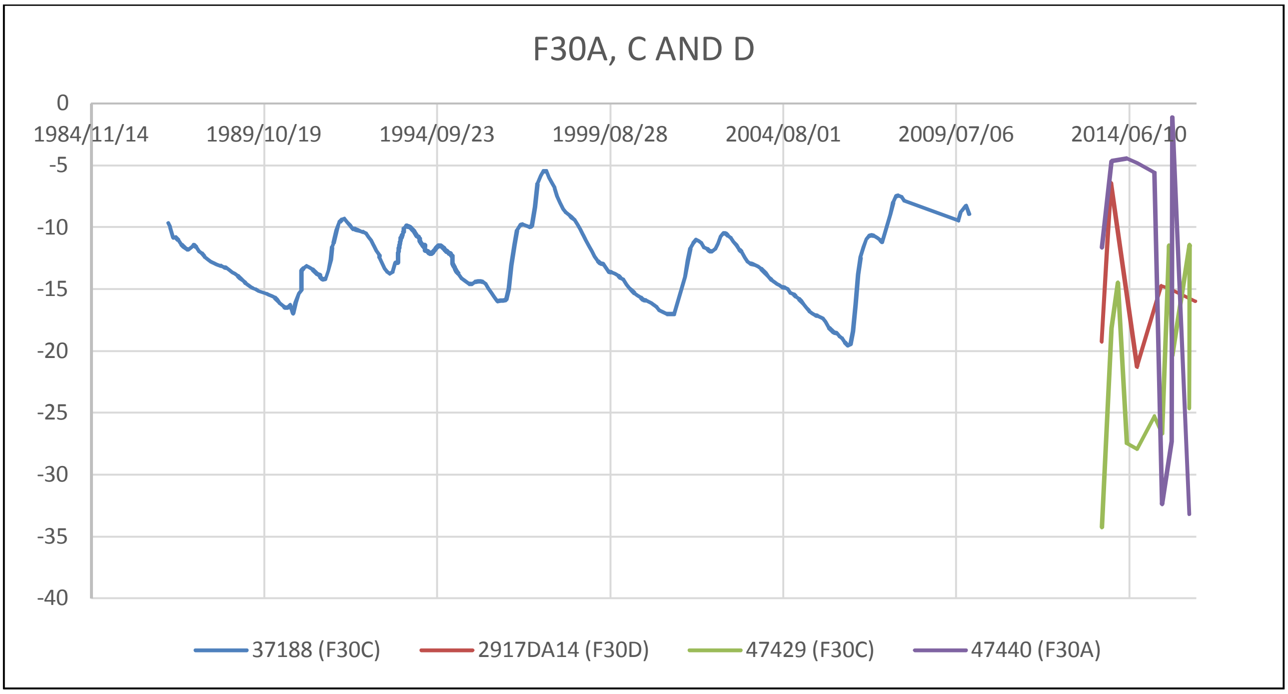


Figure 4.50 Water levels in F30A, F30C and F30D in mbgl

Table 4-35 Namaqualand East: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D82D	111	31	915	0.05		0.029			0.004	0.000	0.033	0.004	0.66	E
F30A	162	100	1951	1.24	0.005	0.087	0.000	0.000	0.021	0.056	0.169	0.077	0.14	B
F30B	107	100	1460	0.38	0.016	0.065	0.000	0.000	0.005	0.008	0.095	0.014	0.25	C
F30C	184	100	1651	1.94	0.000	0.074	0.000	0.000	0.012	0.160	0.245	0.172	0.13	B
F30D	162	100	974	0.62	0.180	0.044	0.000	0.000	0.009	0.886	1.119	0.895	1.80	F
F30E	153	100	1257	0.69	0.000	0.056	0.000	0.000	0.015	0.022	0.093	0.037	0.13	B
Total			8208	4.93	0.201	0.354	0.000	0.000	0.066	1.132	1.753	1.198		

Table 4-36 Namaqualand East: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D82D	4.06	0	0.005	0.005	0.010			Low
F30A	43.41	0	0.027	0.027	0.694	Record too short		Low
F30B	44.29	0	0.007	0.007	0.184			Low
F30C	81.67	0	0.015	0.015	1.102	Record stops in 2010		Low
F30D	54.96	0	0.012	0.012	**-0.326***	Record too short		High
F30E	67.55	0	0.019	0.019	0.386			Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Table 4-37 Namaqualand East: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D82D	1	4	8	7	3	4	17	35	30	13	57
F30A	10	13	10	4	5	24	31	24	10	12	79
F30B	0	1	0	2	3	0	17	0	33	50	17
F30C	7	20	10	18	12	10	30	15	27	18	55
F30D	1	2	8	5	4	5	10	40	25	20	55
F30E	1	4	3	4	2	7	29	21	29	14	57

4.3.13 Namaqualand West

The GRU consists of the foothills of the Namaqualand uplands and the upper margin of the coastal plain. It is drained by rivers that flow to the Atlantic Ocean (Figures 4.51 and 4.52).

The Namaqualand West GRU is underlain by rocks of the Nama and Vanrhynsdorp Groups. Along the coast, they are covered by Tertiary and Quaternary sediments. Recharge is less than 1 mm but can range to over 3 mm in the Garies vicinity, due to higher rainfall in the highlands. The aquifer is of the fractured and weathered type and mean borehole yields are low, being 0.1 - 0.5 l/s. Groundwater levels are from 12 to 50 mbgl, being deeper near the coast.

Groundwater is generally of Poor to Unacceptable quality, Class 3 - 4. Arsenic and Molybdenum are also present. Groundwater can be of very variable quality, and areas of Class 0 - 2 water also exist, however, less than 40% of boreholes are potable (Table 4.40).

The Garies cluster to Kamaggas is reliant on groundwater and most groundwater use is for water supply for the communities of Kamaggas and Garies. De Beers and Bontekoe mine also are significant water users (Table 4.38). The stress index is low, except in F30G where mining takes place. Kamaggas also abstracts water from this catchment, however, at a significant distance from De Beers. No water level data is available to determine the level of stress. Groundwater level data in other catchments do not indicate declining water levels (Figures 4.53 to 4.55).

The GRU is moderately to heavily dependent on groundwater for water supply, consequently, where abstraction results in a high stress index, those catchments are considered of high priority (Table 4.39).

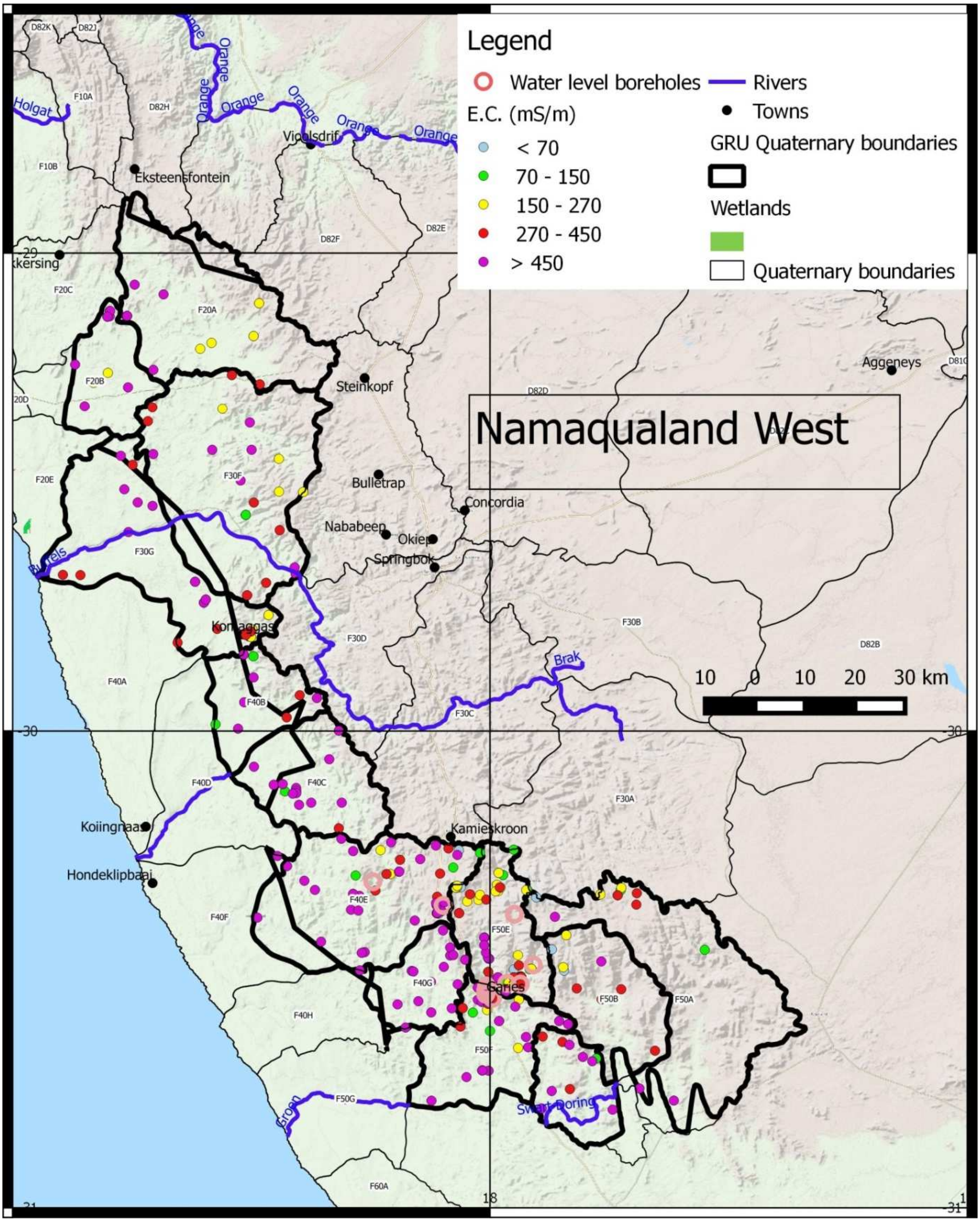


Figure 4.51 Catchments in Namaqualand West GRU and existing monitoring boreholes

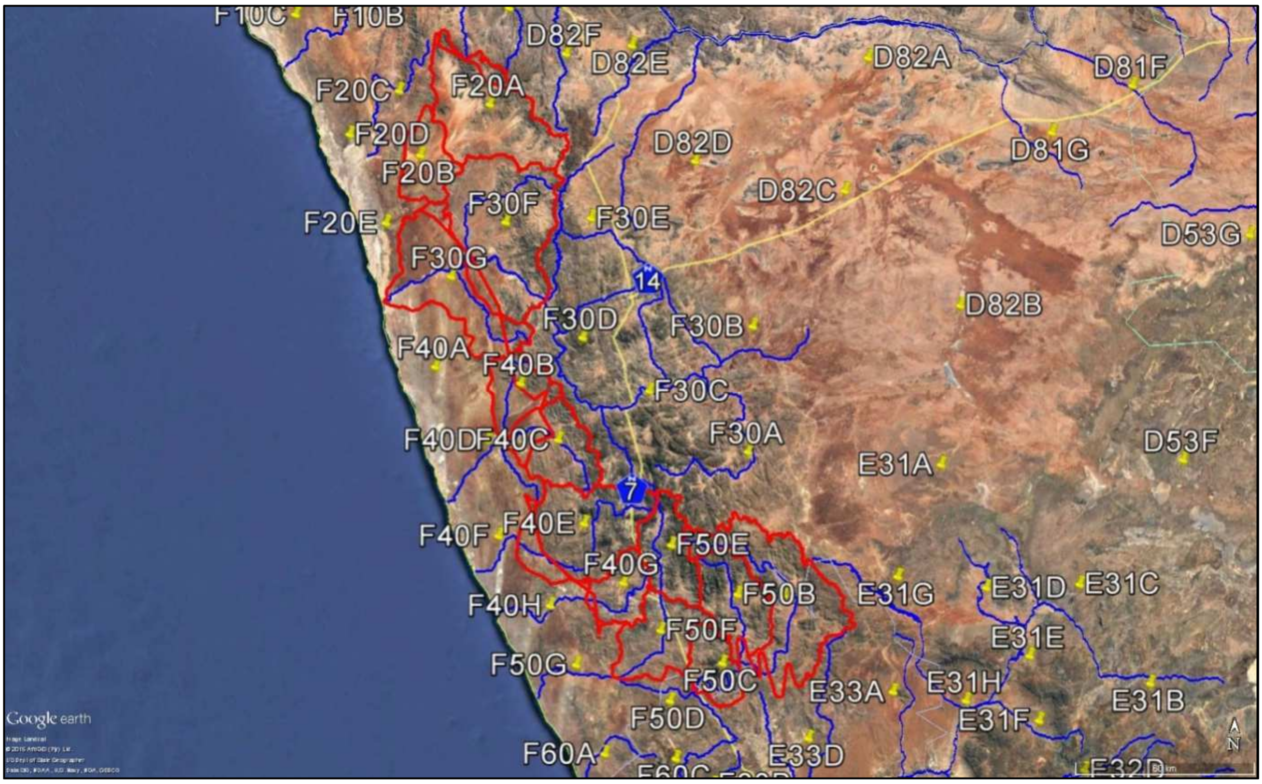


Figure 4.52 Namaqualand West land cover

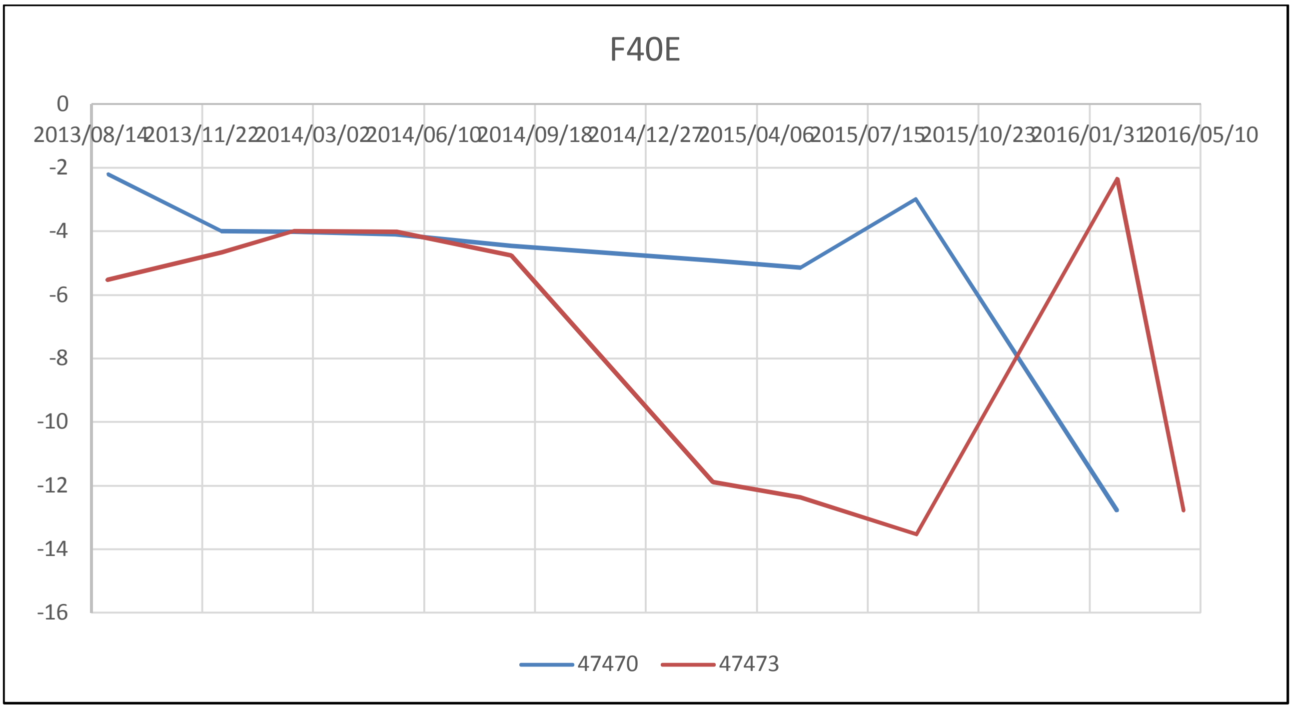


Figure 4.53 Water levels in F40E in mbgl

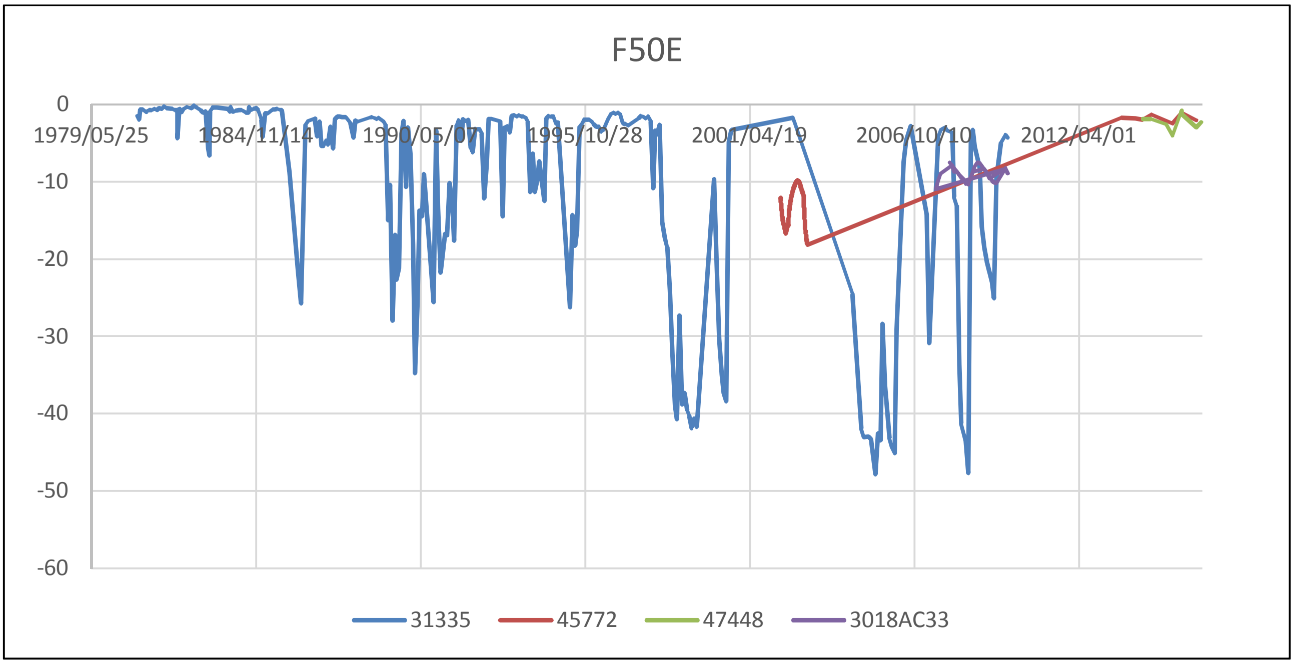


Figure 4.54 Water levels in F50E in mbgl

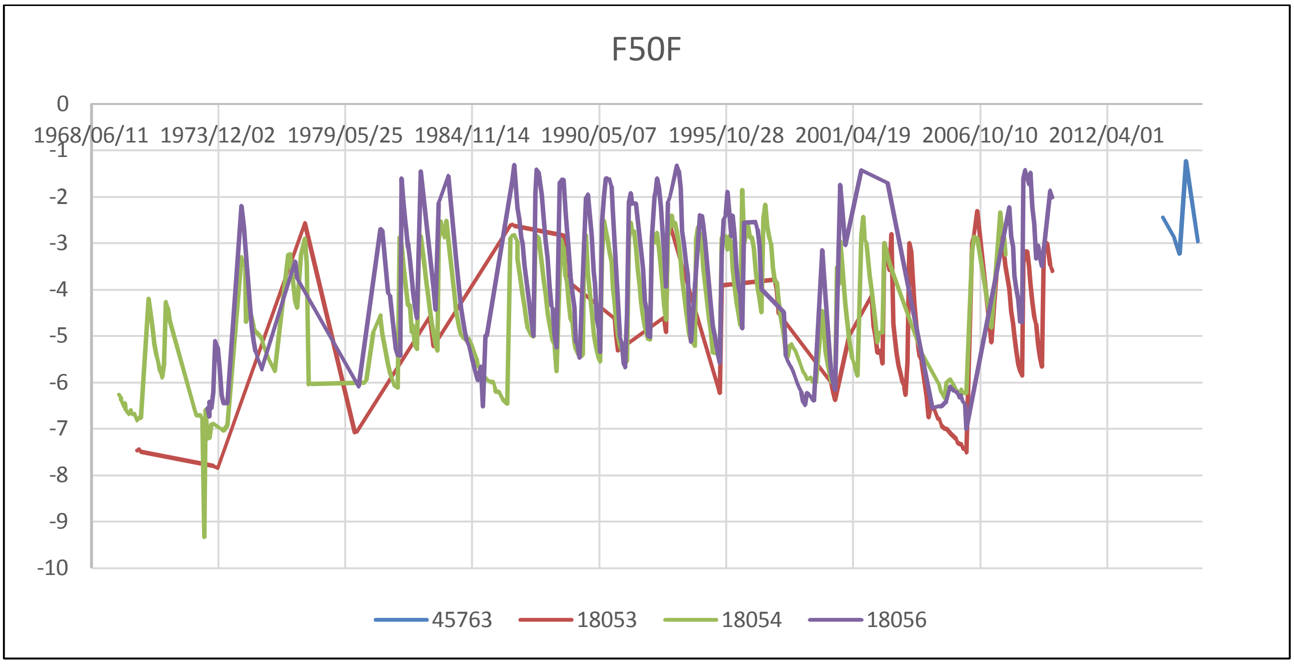


Figure 4.55 Water levels in F50F in mbgl

Table 4-38 Namaqualand West: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
F20A	99	100	1117	0.25	0.000	0.050	0.000	0.000	0.001	0.001	0.052	0.002	0.20	C
F20B	91	66	391	0.08		0.017			0.001	0.000	0.018	0.001	0.23	C
F30F	112	100	1465	0.41	0.000	0.065	0.000	0.000	0.004	0.003	0.072	0.006	0.17	B
F30G	102	100	977	0.23	0.000	0.044	0.757	0.000	0.006	0.262	1.068	0.268	4.57	F
F40B	130	100	403	0.15	0.000	0.018	0.000	0.000	0.001	0.001	0.020	0.002	0.13	B
F40C	173	100	607	1.14	0.000	0.027	0.000	0.000	0.007	0.012	0.046	0.019	0.04	A
F40E	186	100	1062	2.01	0.000	0.047	0.000	0.000	0.008	0.092	0.148	0.100	0.07	B
F40G	168	100	347	0.68	0.000	0.016	0.000	0.000	0.002	0.003	0.020	0.005	0.03	A
F50A	179	100	1303	1.09	0.000	0.029	0.000	0.000	0.014	0.006	0.049	0.020	0.04	A
F50B	208	100	603	0.81	0.023	0.027	0.000	0.000	0.002	0.000	0.051	0.002	0.06	B
F50C	159	100	438	0.57	0.000	0.012	0.003	0.000	0.003	0.008	0.026	0.011	0.05	A
F50E	246	100	486	1.60	0.000	0.022	0.000	0.000	0.005	0.009	0.036	0.015	0.02	A
F50F	133	100	574	1.36	0.000	0.026	0.000	0.000	0.004	0.348	0.378	0.352	0.28	C
Total			**9773**	**10.45**	**0.023**	**0.400**	**0.760**	**0.000**	**0.059**	**0.743**	**1.984**	**0.802**		

Table 4-39 Namaqualand West: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
F20A	43.41	0	0.002	0.002	0.132			Low
F20B	44.29	0	0.001	0.001	0.039			Low
F30F	46.63	0	0.005	0.005	0.221			Low
F30G	94.23	0	0.008	0.008	**-0.544**[*]			High
F40B	49.54	0	0.002	0.002	0.086			Low
F40C	82.12	0	0.009	0.009	0.711			Low
F40E	93.37	0	0.011	0.011	1.207	Record too short		Low
F40G	97.78	0	0.003	0.003	0.430			Low
F50A	70.91	0	0.017	0.017	0.677			Low
F50B	73.68	0	0.002	0.002	0.494			Low
F50C	64.67	0	0.004	0.004	0.353			Low

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
F50E	96.7	0	0.007	0.007	1.015	Y	3	Low
F50F	96.37	0	0.005	0.005	0.638	Y		Intermediate

* **Red text indicates negative allocable groundwater, therefore the quat is already over utilised.**

Table 4-40 Namaqualand West: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
F20A	0	0	4	1	5	0	0	40	10	50	40
F20B	0	0	2	4	7	0	0	15	31	54	15
F30F	0	1	4	7	7	0	5	21	37	37	26
F30G	0	7	2	8	8	0	28	8	32	32	36
F40B	0	2	0	2	5	0	22	0	22	56	22
F40C	0	1	0	1	12	0	7	0	7	86	7
F40E	4	3	2	8	25	10	7	5	19	60	21
F40G	0	0	0	0	14	0	0	0	0	100	0
F50A	1	2	2	4	6	7	13	13	27	40	33
F50B	2	0	2	4	2	20	0	20	40	20	40
F50C	0	1	0	3	9	0	8	0	23	69	8
F50E	7	8	16	11	10	13	15	31	21	19	60
F50F	2	2	4	6	22	6	6	11	17	61	22

4.3.14 Taung-Prieska Belt

The GRU consists of eastern Kalahari bushveld adjacent to the Vaal and Orange Rivers. The two rivers join in the northeast of the GRU and the Ongers River joins the Orange near Prieska, which marks the western border of the GRU (Figures 4.56 and 4.57).

The Taung-Prieska Belt is underlain by Dwyka tillite and, Ventersdorp Supergroup rocks, with extensive Tertiary cover covering much of the GRU. Recharge is from 3.5 mm/a near Prieska rising to 9.5 mm/a near Douglas. The aquifer is of the fractured type and mean borehole yields are 0.5 - 1.5 l/s. Groundwater levels are 15 - 20 mbgl.

Groundwater quality is of Class 1 - 2, which is Good to Marginal, however, elevated nitrates can occur. Class 3 water is found in D72A near Prieska. The potability of groundwater ranges from 76% near Prieska to 100% (Table 4.43).

No towns rely on groundwater. Groundwater use is primarily for irrigation and livestock, with the major towns obtaining water from the Orange and Vaal systems (Table 4.41). The stress index is low due to the low level of groundwater usage. Groundwater levels in D62G and D72A indicate that water levels are stable (Figures 4.58 and 4.59).

The GRU is moderately to heavily dependent on groundwater for Schedule 1 water use in areas at a distance from Orange River water. However, due to the low stress indices, all of the catchments are considered of low priority (Table 4.42).

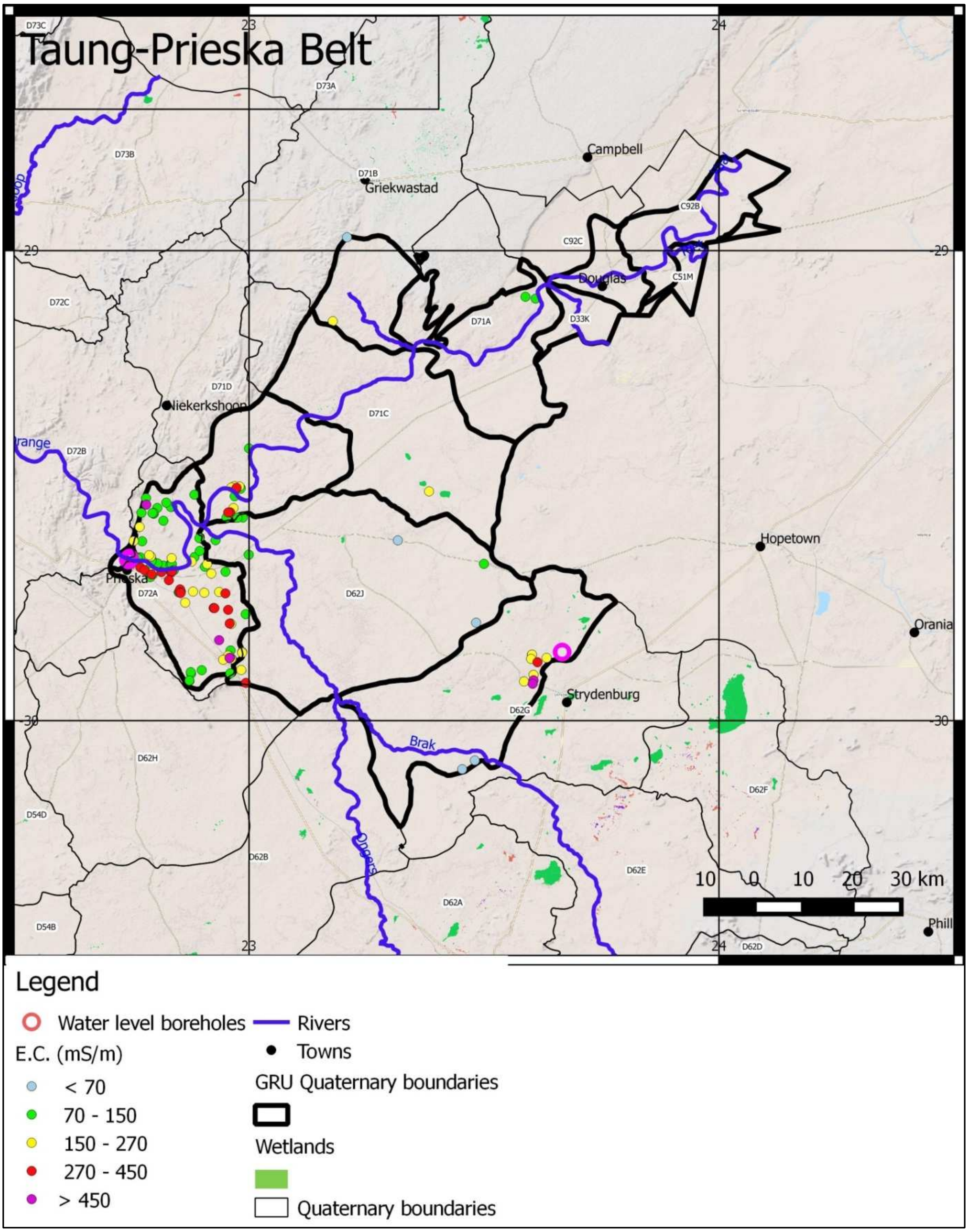


Figure 4.56 Catchments in the Taung-Prieska Belt GRU and existing monitoring boreholes

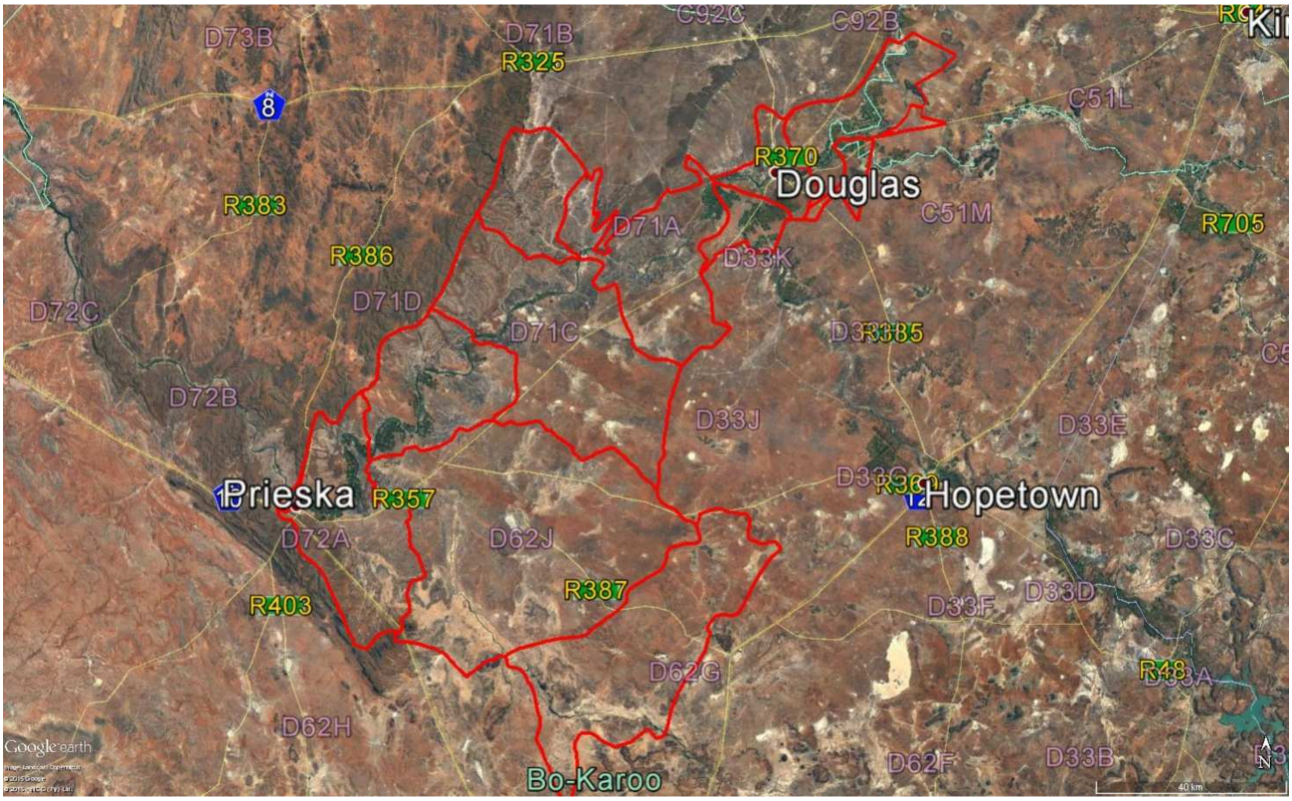


Figure 4.57 Taung-Prieska Belt land cover

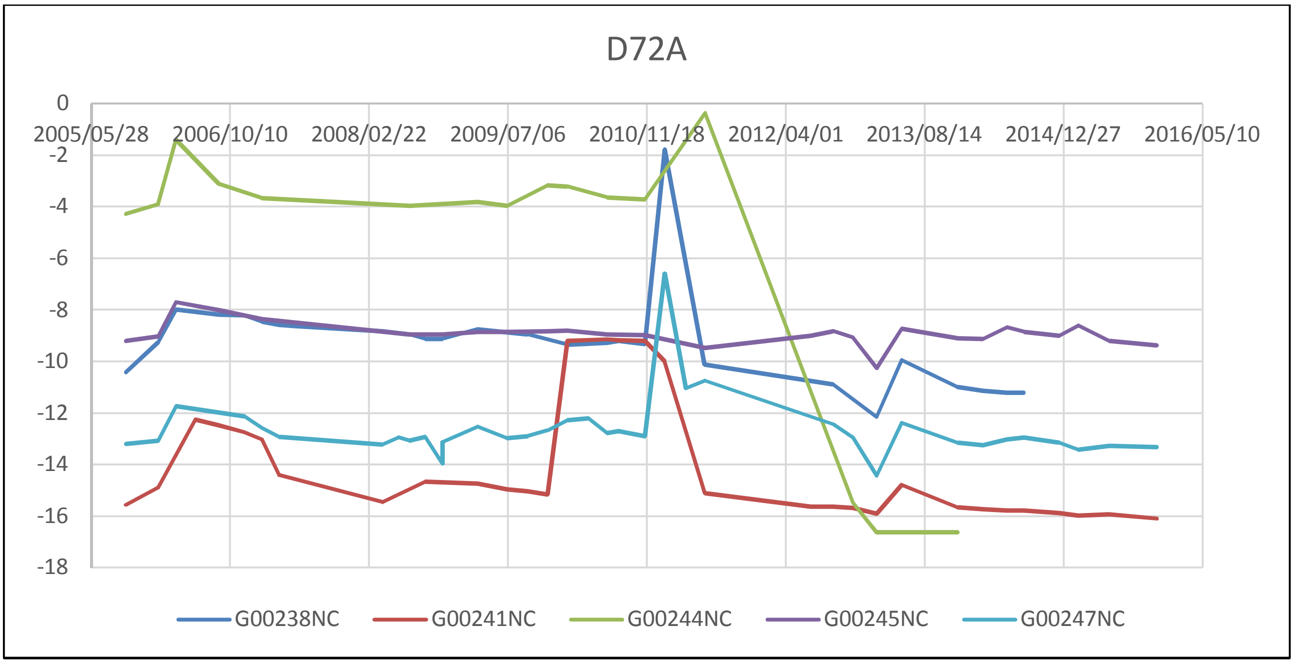


Figure 4.58 Water levels in D72A

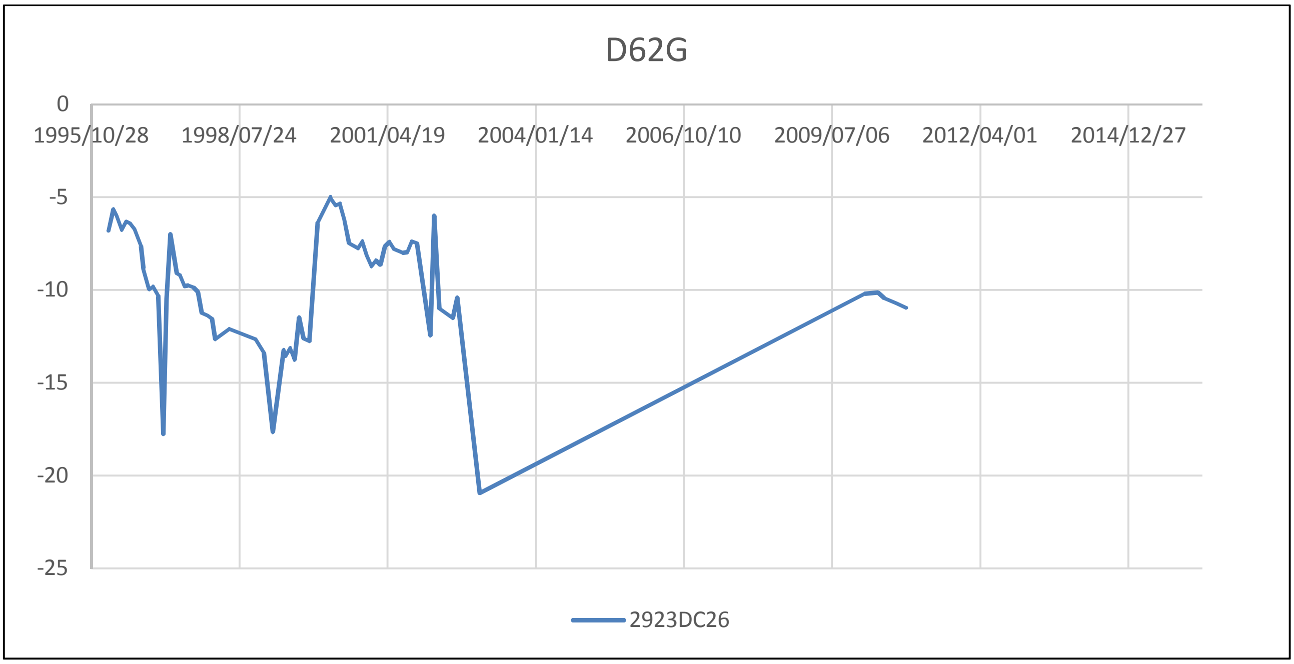


Figure 4.59 Water levels in D62G

Table 4-41 Taung-Prieska Belt: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
C51M	350	100	119	0.84	0.000	0.001	0.000	0.000	0.026	0.000	0.027	0.026	0.03	A
C92B	331	70	446	3.40		0.064			0.057	0.000	0.122	0.057	0.04	A
C92C	326	34	211	2.02		0.016			0.039	0.000	0.054	0.039	0.03	A
D33K	287	100	158	1.44	0.000	0.005	0.000	0.000	0.007	0.000	0.012	0.007	0.01	A
D62G	256	48	1216	7.70	0.702	0.083		0.050	0.074	0.000	0.910	0.074	0.12	B
D62J	231	100	2198	10.13	0.122	0.142	0.000	0.018	0.021	0.001	0.304	0.022	0.03	A
D71A	283	64	772	5.33	0.011	0.060	0.085		0.012	0.000	0.167	0.012	0.03	A
D71B	315	15	392	2.90	0.035	0.025	0.026		0.009	0.000	0.095	0.009	0.03	A
D71C	250	85	1358	5.98	0.006	0.088	0.014	0.000	0.017	0.001	0.125	0.018	0.02	A
D71D	248	38	656	2.70		0.038	0.000	0.000	0.011		0.048	0.011	0.02	A
D72A	210	56	789	2.75	0.048	0.012			0.010	0.000	0.070	0.010	0.03	A
Total			**8314**	**45.18**	**0.924**	**0.534**	**0.125**	**0.068**	**0.282**	**0.002**	**1.935**	**0.284**		

Table 4-42 Taung-Prieska Belt: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
C51M	53.90	0	0.033	0.033	0.523			Low
C92B	51.73	0	0.074	0.074	2.121			Low
C92C	6.18	0	0.049	0.049	1.268			Low
D33K	7.56	0	0.010	0.010	0.924			Low
D62G	95.21	0	0.097	0.097	4.398	Y	5	Low
D62J	70.52	0	0.027	0.027	6.384			Low
D71A	61.22	0	0.015	0.015	3.353			Low
D71B	92.62	0	0.012	0.012	1.824			Low
D71C	64.61	0	0.022	0.022	3.805			Low
D71D	87.25	0	0.014	0.014	1.719			Low
D72A	10.32	0	0.013	0.013	1.738	Y	1	Low

Table 4-43 Taung-Prieska Belt: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
C51M											
C92B											
C92C	15	74	13	1	0	15	72	13	1	0	99
D33K											
D62G	3	40	19	4	5	4	56	27	6	7	87
D62J	2	5	1	1	0	22	56	11	11	0	89
D71A	0	11	0	0	0	0	100	0	0	0	100
D71B	16	43	1	1	0	26	70	2	2	0	98
D71C	1	0	1	0	0	50	0	50	0	0	100
D71D	3	18	12	3	0	8	50	33	8	0	92
D72A	2	60	46	26	8	1	42	32	18	6	76

4.3.15 West Griqualand

The GRU consists of eastern Kalahari bushveld. The Orange River flows through the GRU below Prieska (Figures 4.60 and 4.61).

The West Griqualand GRU is underlain by the Olifantshoek Supergroup, the Ventersdorp Super Group, some dolomites, and Transvaal Group ironstones. Recharge is from 2 - 6 mm/a and increases from west to east. The aquifer is of the fractured type and mean borehole yields are low, being 0.5 - 1 l/s. Groundwater levels are 20 - 35 mbgl.

Groundwater quality is of Class 1 - 2 but elevated nitrates can occur. Towards the west, south of the Orange River, some Class 2 and 3 boreholes are found near the margins of the Bushmanland East GRU. The potability of groundwater is over 90% (Table 4.46).

Niekerkshoop is reliant on groundwater. Otherwise, groundwater use is primarily for irrigation and livestock (Table 4.44). The stress index is low due to the low level of groundwater usage. Groundwater levels only indicate a drop of about 1 m over the period of record (Figures 4.62 to 4.64).

The GRU is moderately to heavily dependent on groundwater for Schedule 1 water use and for Niekerkshoop, however, due to the low stress indices, all of the catchments are considered of low priority (Table 4.45).

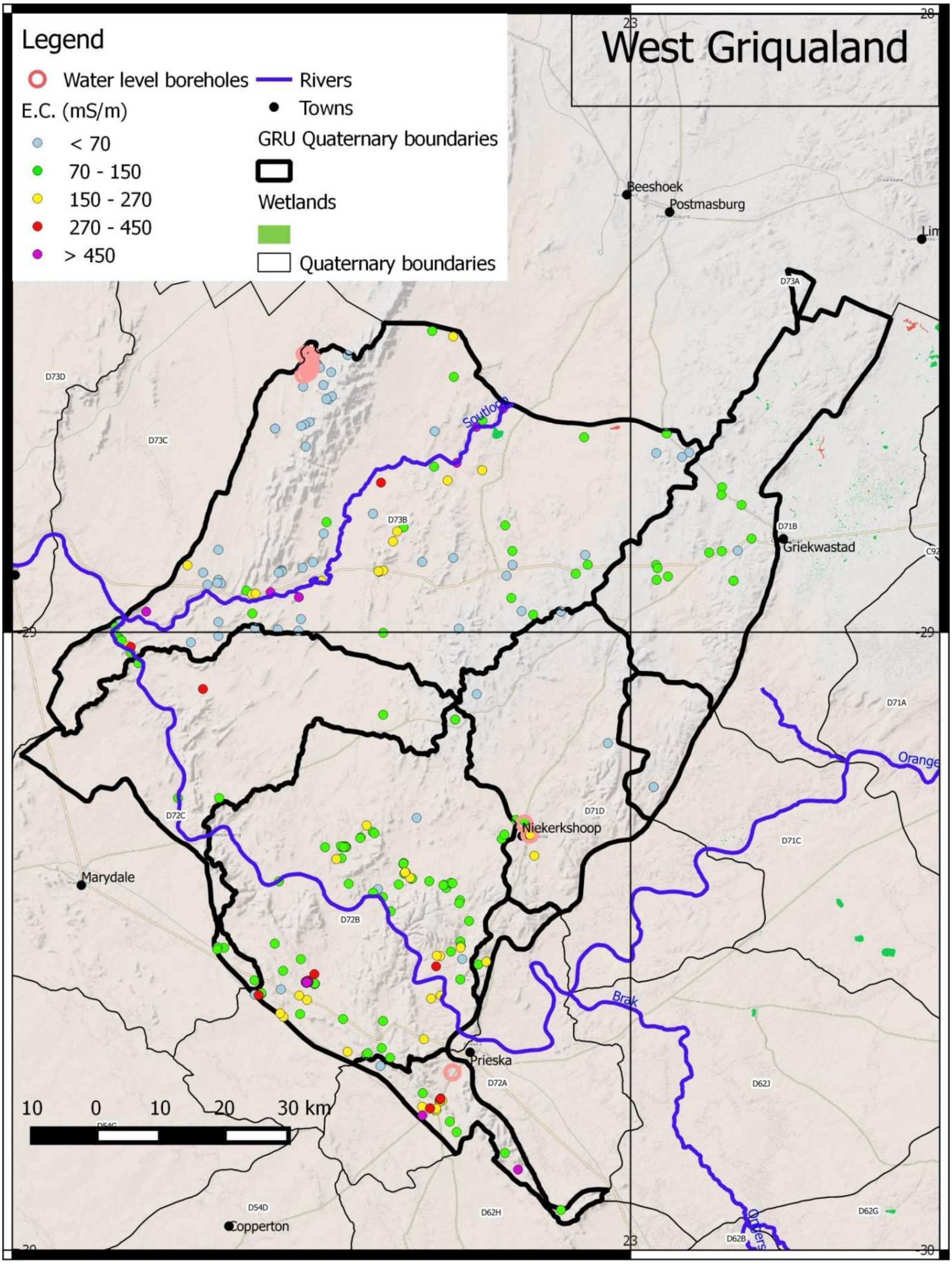


Figure 4.60 Catchments in West Griqualand GRU and existing monitoring boreholes

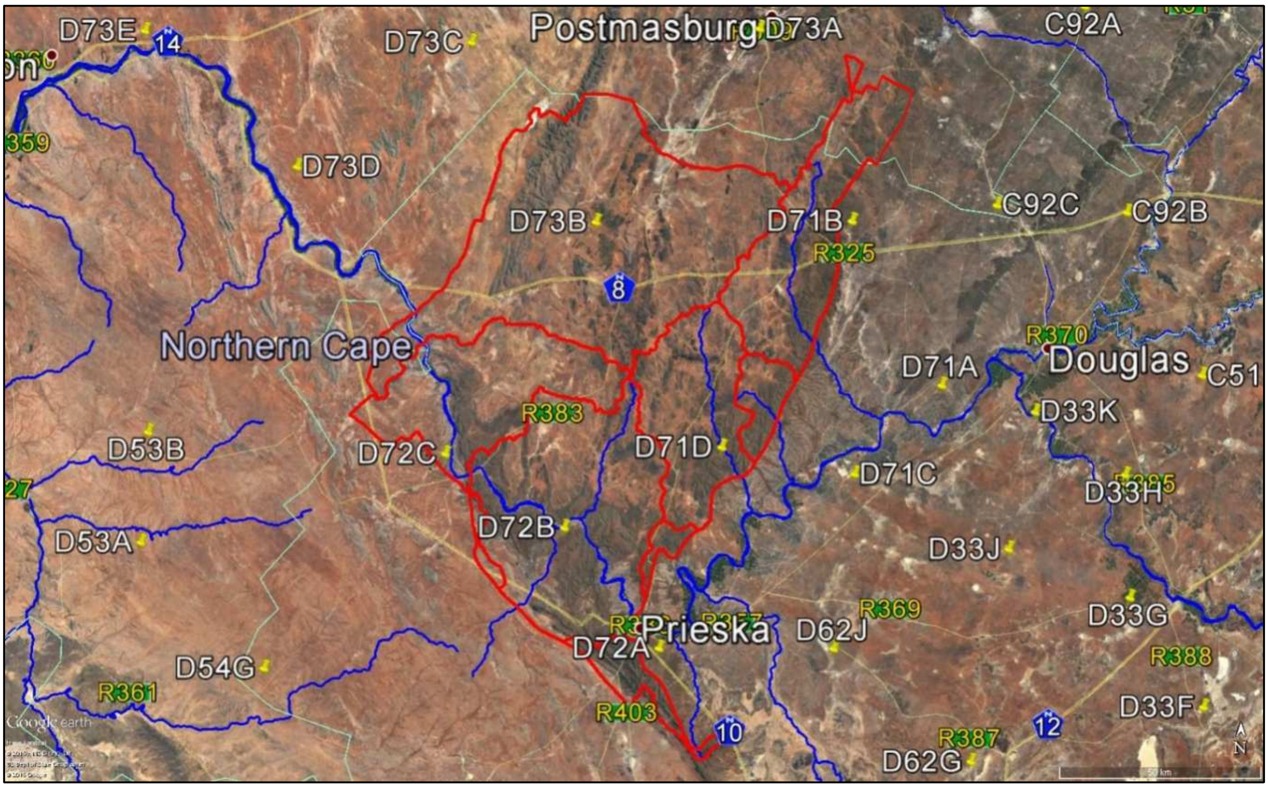


Figure 4.61 West Griqualand land cover

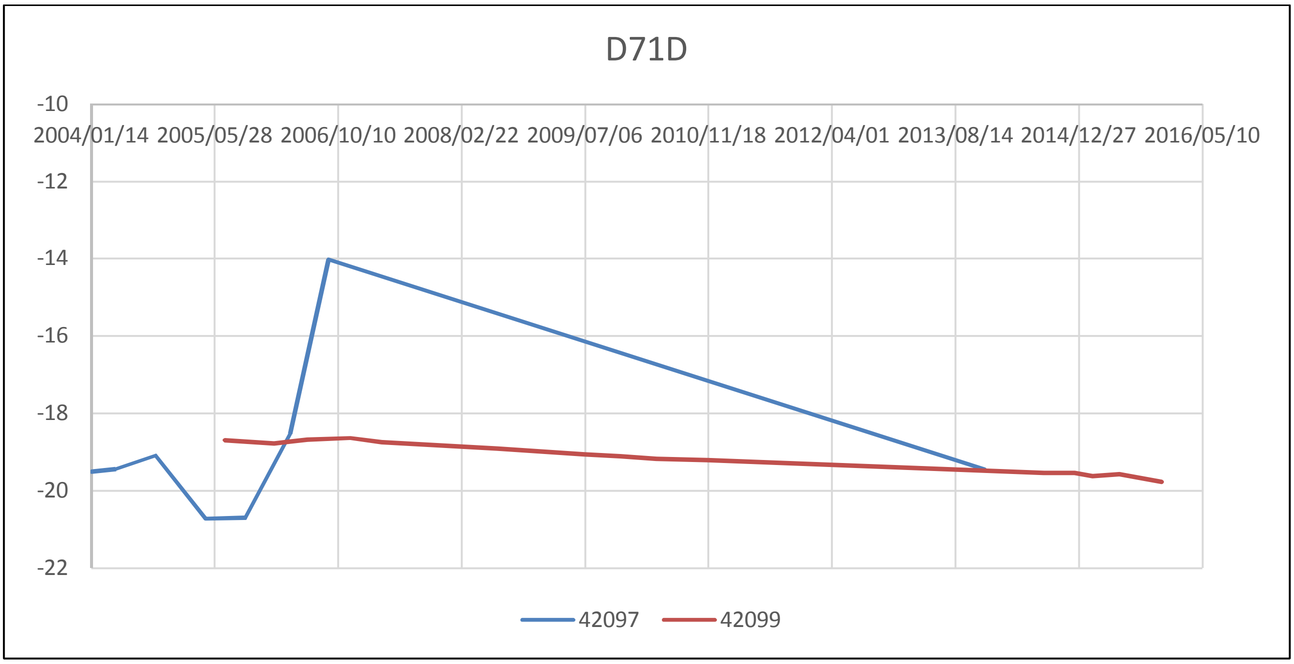


Figure 4.62 Water levels in D71D in mbgl

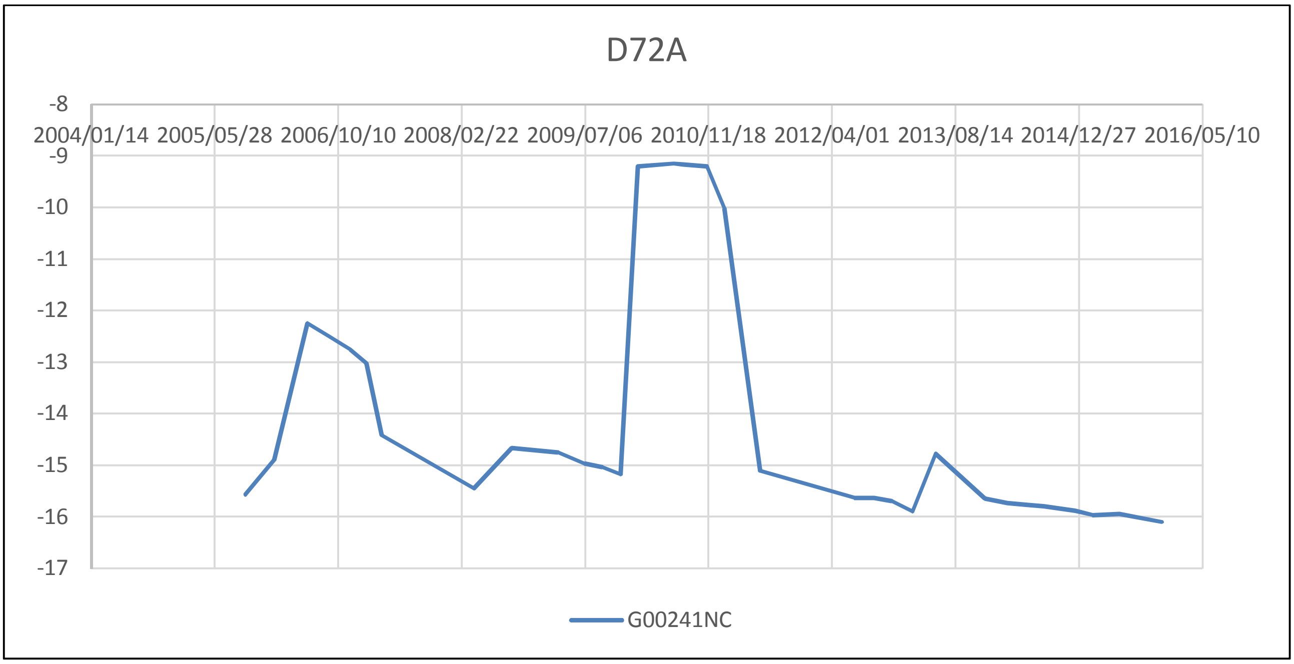


Figure 4.63 Water levels in D72A in mbgl

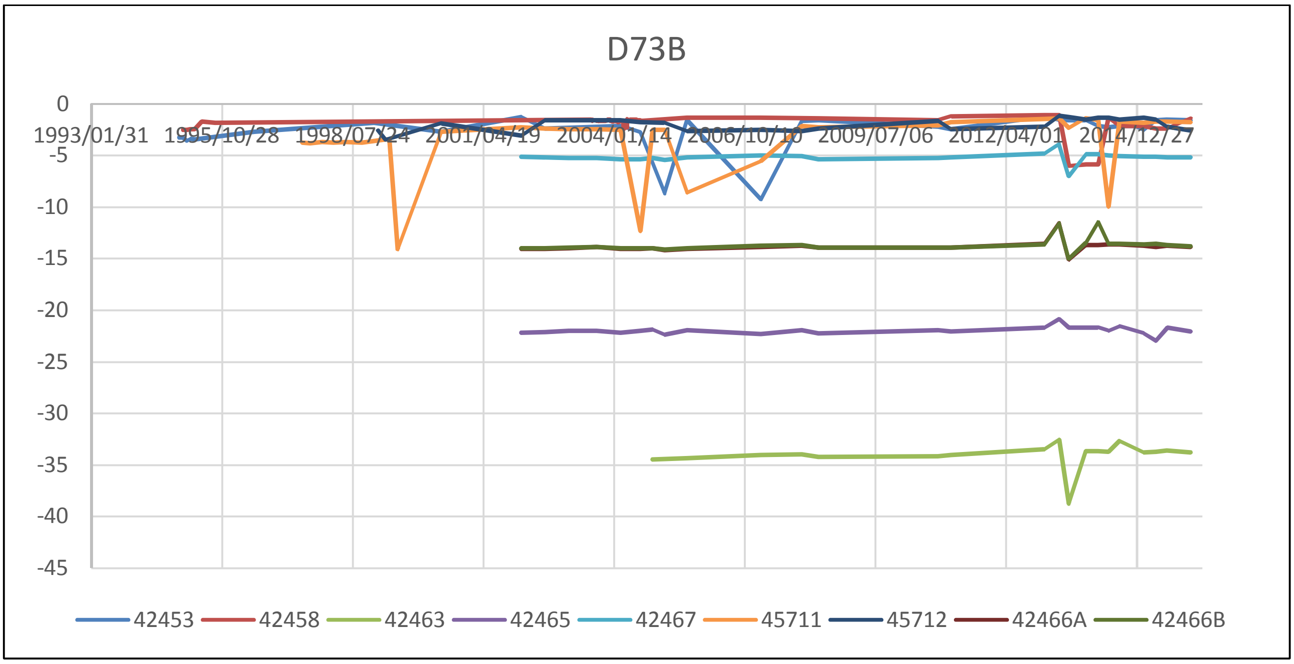


Figure 4.64 Water levels in D73B in mbgl

Table 4-44 West Griqualand: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km^2)	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D71B	315	47	1245	9.22	0.213	0.080	0.046		0.029	0.000	0.368	0.029	0.04	A
D71C	250	15	232	1.02		0.015			0.003	0.000	0.018	0.003	0.02	A
D71D	248	62	1056	4.34	0.394	0.061			0.017	0.000	0.471	0.017	0.11	B
D72A	210	24	335	1.17	0.140	0.005			0.004	0.000	0.149	0.004	0.13	B
D72B	215	84	2152	6.52	0.164	0.031	0.004		0.036	0.000	0.235	0.036	0.04	A
D72C	200	50	1382	2.61	0.002	0.016			0.021	0.000	0.039	0.021	0.01	A
D73B	258	100	3522	18.31	0.272	0.199	0.117	0.000	0.060	0.004	0.652	0.064	0.04	A
Total			**9923**	**43.20**	**1.185**	**0.407**	**0.166**	**0.000**	**0.170**	**0.152**	**2.081**	**0.322**		

Table 4-45 West Griqualand: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D71B	92.62	0	0.038	0.038	5.75			Low
D71C	64.61	0	0.004	0.004	0.65			Low
D71D	87.25	0	0.023	0.023	2.42	Y		Low
D72A	10.32	0	0.005	0.005	0.66	N	1	Low
D72B	4.47	0	0.046	0.046	4.08			Low
D72C	89.10	0	0.027	0.027	1.67	Y	1	Low
D73B	57.83	0.11163	0.190	0.302	11.39			Low

Table 4-46 West Griqualand: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D71B	16	43	1	1	0	26	70	2	2	0	98
D71C	1	0	1	0	0	50	0	50	0	0	100
D71D	3	18	12	3	0	8	50	33	8	0	92
D72A	2	60	46	26	8	1	42	32	18	6	76
D72B	7	91	33	12	11	5	59	21	8	7	85
D72C	5	66	33	8	4	4	57	28	7	3	90
D73B	59	23	12	2	6	58	23	12	2	6	92

4.3.16 Western Kalahari

The GRU consists of largely of Kalahari duneveld. The Molopo River flowing through the GRU does generate sufficient flow to reach the Orange River and much of the flood is lost by evaporation, or seepage to recharge the sand aquifer. This process makes recharge estimation based purely on rainfall problematic and recharge may be higher than estimated (Figures 4.65 and 4.66).

The Western Kalahari GRU consists of Quaternary sand cover overlying largely Dwyka tillite, Koras Group sandstone, or metamorphics of the Kaaien Terrane. Recharge is less than 1 mm. Three aquifer types exist:

- The surficial intergranular Kalahari sand aquifer, which has yields of 0.5 - 2 l/s;
- The Stampriet confined aquifer system, which underlies the Kalahari in the north and is fractured in nature. It has low yields of 0.1 - 0.5 l/s;
- Other fractured aquifers of the Dwyka, Brulpan Volop and Koras Groups, which have yields of 0.5 - 2 l/s.

Groundwater levels are from 25 to 90 mbgl, being deepest in the northern Kalahari.

The Stampriet Transboundary Aquifer System (STAS) is of sufficient importance to be discussed separately, since it is an international aquifer. The aquifer stretches from Central Namibia into Western Botswana and into South Africa. It covers a total area of 86 647km², for which 73% of the area is in Namibia, 19% in Botswana, and 8% is in South Africa. It is not exposed at surface in South Africa and underlies the Kalahari sands in D42A-D. The aquifer is made up of two deep confined artesian transboundary aquifers in the Karoo sediments (Auob and Nossob sandstone aquifers of the Ecca Group), overlain by an unconfined aquifer system in the Kalahari sediments (Kalahari intergranular aquifer). The mean annual recharge rate for these confined aquifer units is likely to be significantly less than that of the Kalahari aquifers due to the lack of outcrop. Recharge to the Auob and Nossob aquifers in normal rainfall years is negligible but considerable recharge occurs during extreme rainfall events. The general groundwater flow is from northwest to southeast; hence, the South African portion receives groundwater from Namibia.

Over 20 million m³/year are abstracted rom the Stampriet aquifer, most of which occurs in Namibia (over 95%). The largest consumer of water is irrigation (~46%) followed by stock watering (~38%) and domestic use (~16%).

In the Southeastern quadrant of the aquifer within South Africa, groundwater seeps upward from the confined aquifers and discharges into the Kalahari Formations, from where it evaporates in pans and wetlands. Groundwater salinity in this zone therefore is rather high.

In South Africa, the aquifer has only limited potential for further development because, apart from the poor water quality, the permeability and storativity is low.

Groundwater quality in the GRU generally of Poor to Unacceptable quality, being largely of Class 3 and 4, and only improves in the SE around Karos and Grootdrink in the D73 catchments, where it is of Class 2. In the Kalahari sands, groundwater can be very alkaline. Nitrates are fluorides are elevated in the GRU. In the D73 catchments the Kalahari sands are thinner and recharge is higher hence groundwater quality improves. Fresh groundwater also exists near Philandersbron, where the Kalahari cover disappears and Karoo rocks are exposed, and wetlands exist. The potability of groundwater is about 20% over large parts of the region, and nearly 80% in the D73 catchments (Table 4.49).

The Rietfontein and Mier cluster of communities are reliant on groundwater from fractured Dwyka aquifers. Groundwater use is primarily for livestock and water supply, which the remainder for salt mining (Table 4.47). The stress index is low due to the low level of groundwater usage. Groundwater levels only indicate a slight drop of about 1 m over the period of record (Figures 4.67 to 4.69).

The GRU is heavily dependent on groundwater for Schedule 1 water use and for water supply to the towns in the Kalahari Panhandle. However, due to the low stress indices, all of the catchments are considered of low priority (Table 4.48).

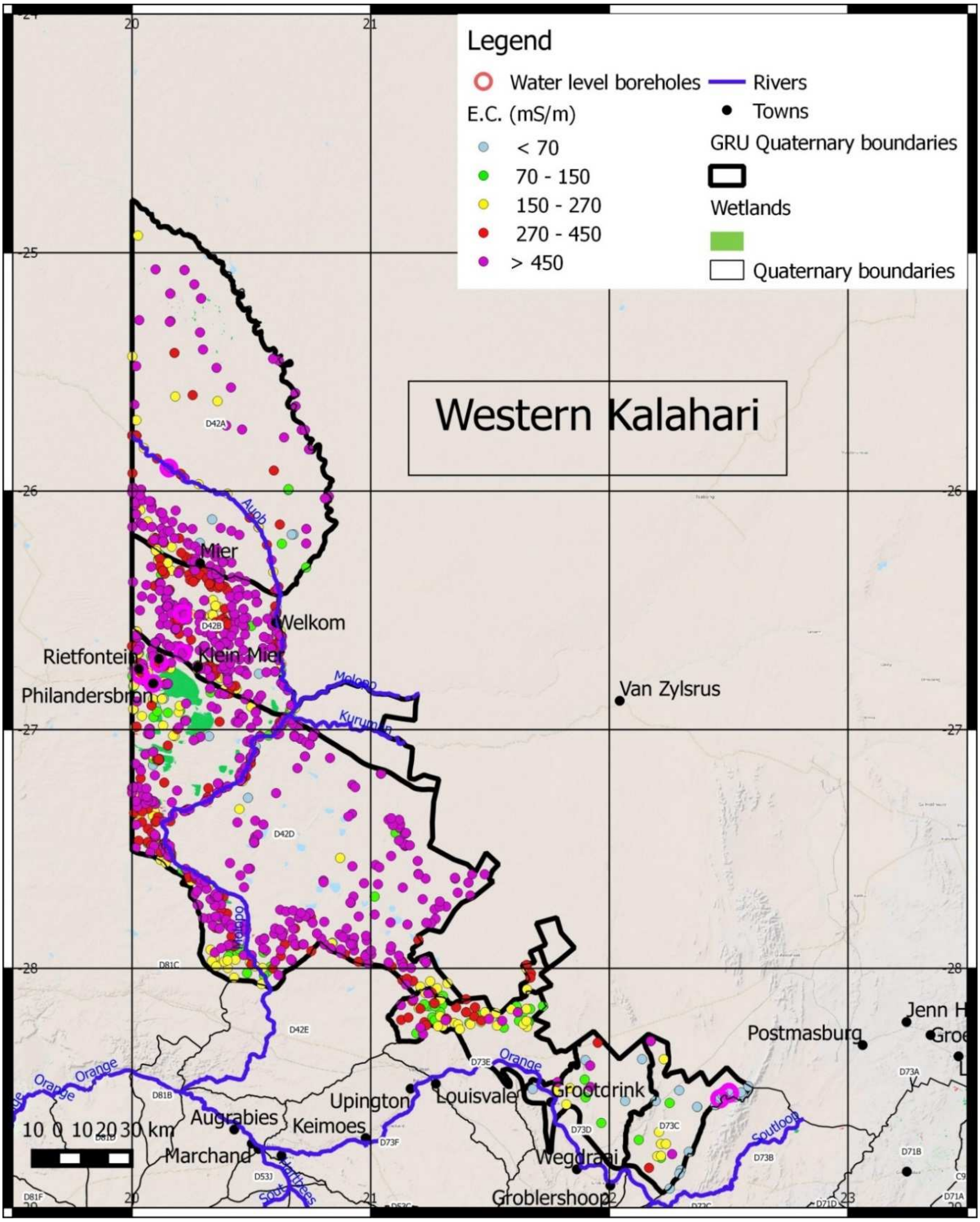


Figure 4.65 Catchments in the Western Kalahari GRU and existing monitoring boreholes

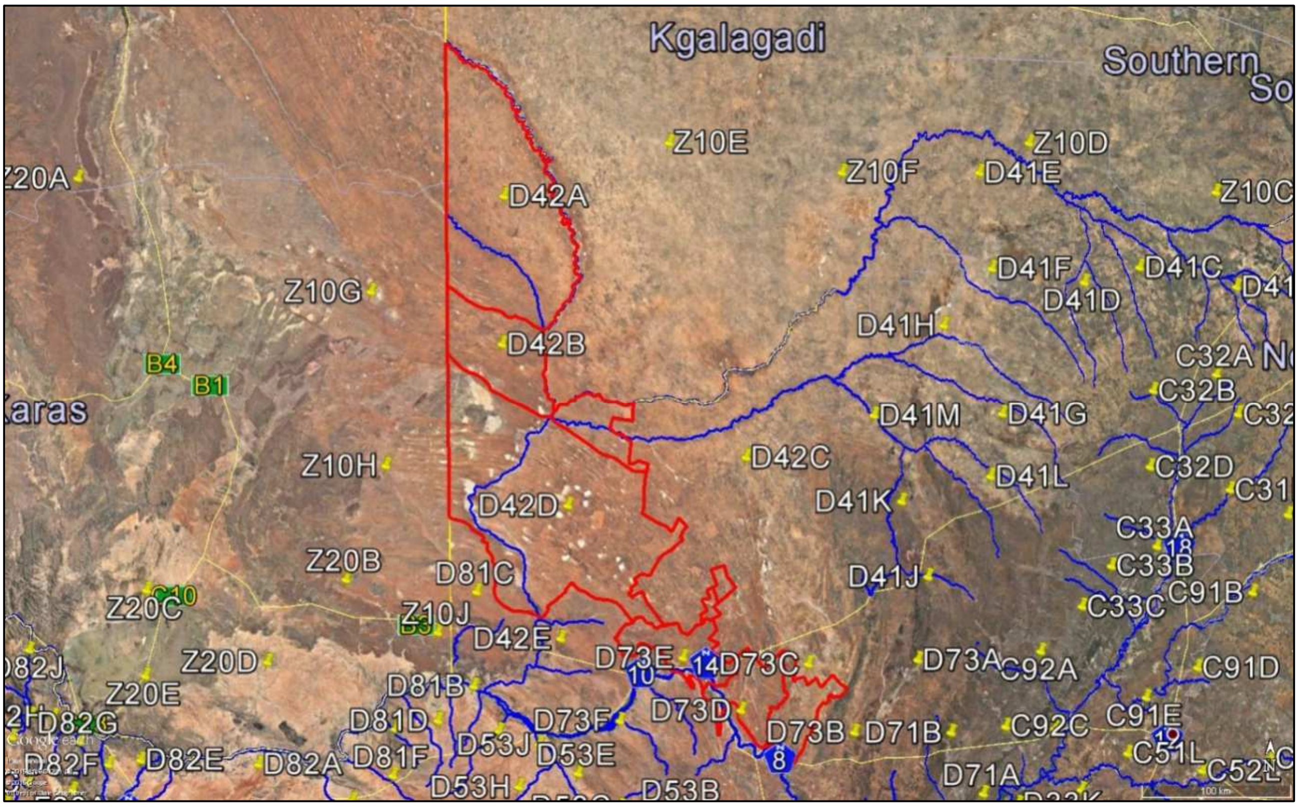


Figure 4.66 Western Kalahari land cover

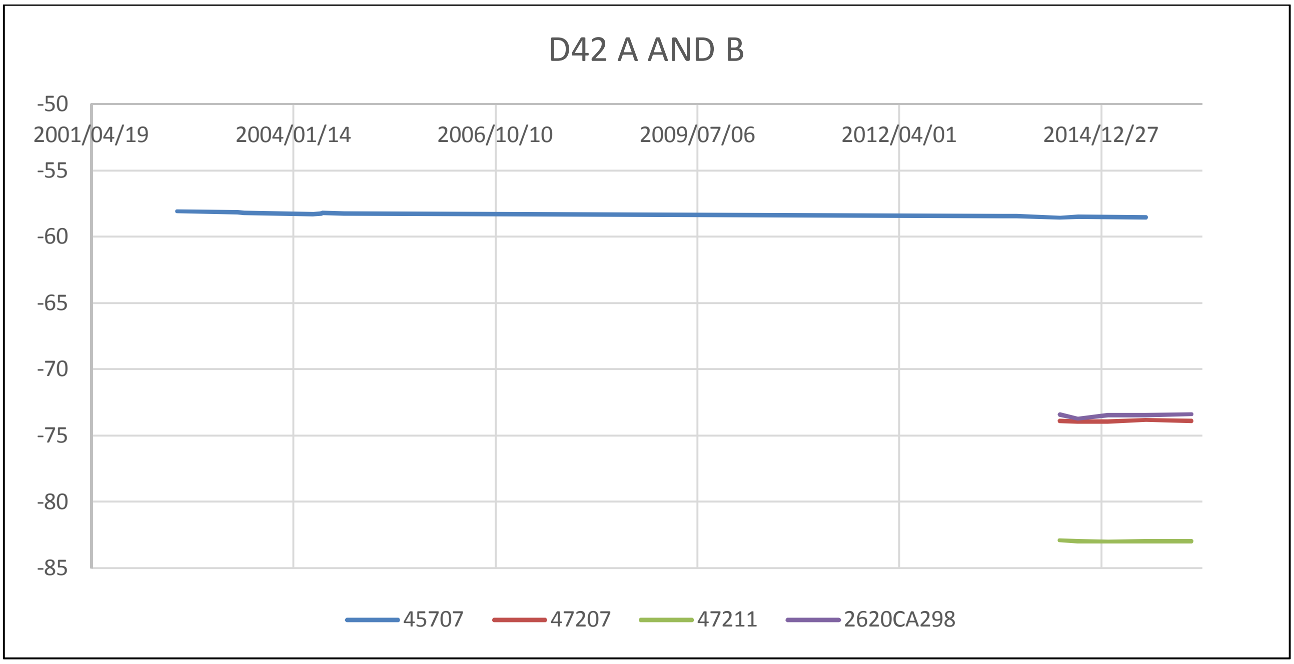


Figure 4.67 Water levels in D42A and D42B in mbgl

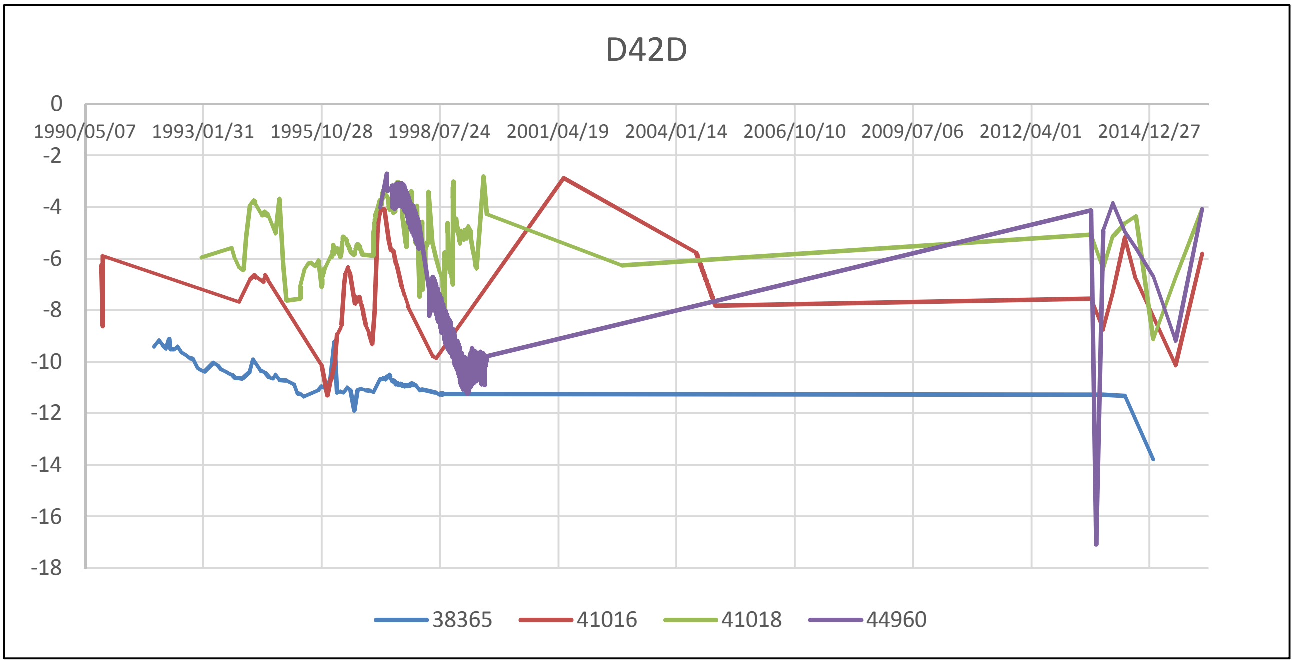


Figure 4.68 Water levels in D42D in mbgl

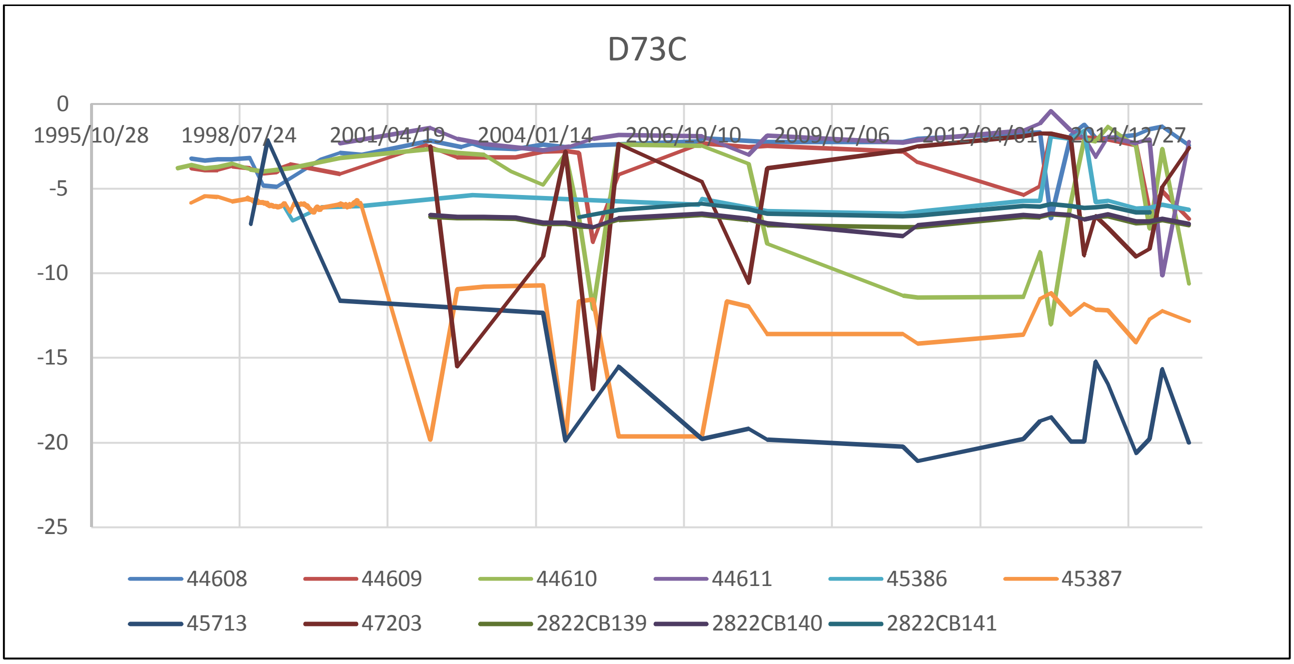


Figure 4.69 Water levels in D73C in mbgl

Table 4-47 Western Kalahari: Groundwater use and stress index

Quat	MAP	Area (km²)	% of Quat	Recharge (Mm^3/a)	Groundwater use (Mm^3/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D42A	222	10273	100	19.79	0.000	0.023	0.000	0.000	0.022	0.150	0.194	0.172	0.01	A
D42B	176	3197	100	1.71	0.000	0.081	0.000	0.007	0.024	0.031	0.143	0.055	0.08	B
D42C	216	1566	100	1.90		0.221	0.000	0.000	0.141		0.362	0.141	0.19	B
D42D	151	14110	100	14.84		0.397	0.384	0.000	0.119	0.137	1.037	0.256	0.07	B
D73C	230	1549	64	5.08		0.141			0.054	0.000	0.195	0.054	0.04	A
D73D	185	1666	44	1.09		0.020			0.023	0.000	0.043	0.023	0.04	A
D73E	183	1746	52	1.10		0.032			0.021	0.000	0.053	0.021	0.05	A
Total		**34107**		**45.51**	**0.000**	**0.915**	**0.384**	**0.007**	**0.403**	**0.318**	**2.027**	**0.721**		

Table 4-48 Western Kalahari: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm^3)	BHN (Mm^3)	GW component of the Reserve (Mm^3)	Allocable GW (Mm^3)	Water level stability (Y/N)	Water level drop (m)	Priority
D42A	84.53	0	0.028	0.028	12.732	N	0.4	Low
D42B	91.94	0	0.031	0.031	1.017		0	Low
D42C	72.42	0	0.183	0.183	1.104			Low
D42D	75.92	0	0.155	0.155	8.979		0	Low
D73C	82.72	0	0.063	0.063	3.172	Y	8	Low
D73D	5.47	0	0.030	0.030	0.677			Low
D73E	2.26	0	0.027	0.027	0.674			Low

Table 4-49 Western Kalahari: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D42A	4	5	26	30	99	2	3	16	18	60	21
D42B	2	18	58	100	186	1	5	16	27	51	21
D42C	0	0	7	2	2	0	0	64	18	18	64
D42D	21	154	142	126	369	3	19	17	16	45	39
D73C	24	9	9	1	1	55	20	20	2	2	95
D73D	4	6	10	6	3	14	21	34	21	10	69
D73E	4	26	33	17	11	4	29	36	19	12	69

4.3.17 Richtersveld

The GRU consists of rocky mountainous desert. The Orange River flows on the northern margin of the GRU (Figures 4.70 and 4.71).

The Richtersveld is underlain by rocks of the Richtersveld Subprovince. Recharge is less than 1 mm. The aquifer is of the fractured and weathered type and mean borehole yields are very low, being 0 - 0.1 l/s. Groundwater levels are from 30 - 50 mbgl, being deeper to the east.

Groundwater is of Marginal to Unacceptable quality, Class 2 - 4. The potability of groundwater ranges from 0 - 60% (Table 4.52).

Eksteenfontein is the only community reliant on groundwater. Groundwater use is primarily for livestock and water supply (Table 4.50). The stress index is moderate to high due to the very low recharge rates.

The GRU is only moderately dependent on groundwater, except for D82H, where Eksteenfontien derives its water supply from boreholes. This catchment is considered to be only of intermediate importance due to the moderate stress index of 0.42 (Table 4.51).

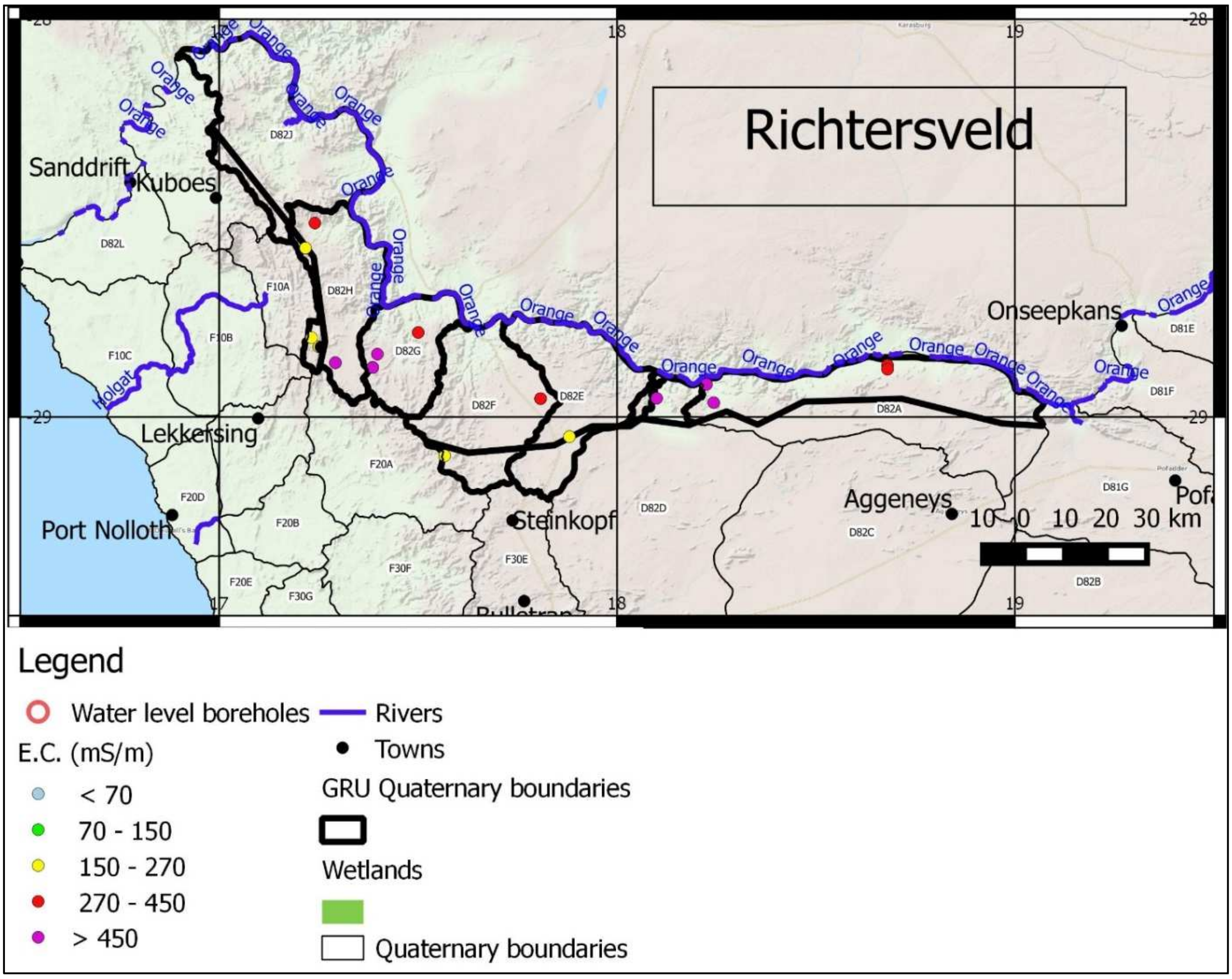


Figure 4.70 Catchments in the Richtersveld GRU and existing monitoring boreholes

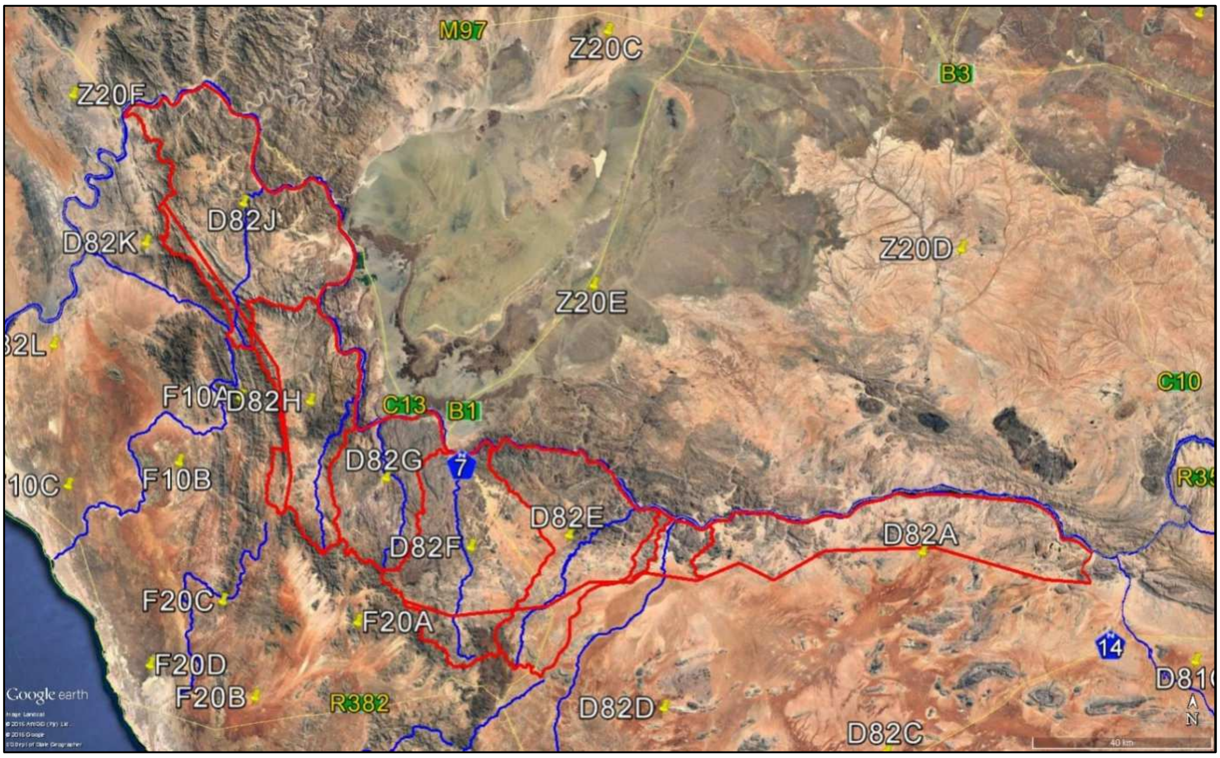


Figure 4.71 Richtersveld land cover

Table 4-50 Richtersveld: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D82A	77	47	894	0.01		0.027			0.004	0.000	0.031	0.004	2.58	F
D82D	111	57	167	0.01		0.005			0.001	0.000	0.006	0.001	0.66	E
D82E	100	100	939	0.22	0.000	0.029	0.000	0.000	0.003	0.002	0.035	0.005	0.16	B
D82F	106	100	1036	0.26	0.000	0.032	0.000	0.000	0.003		0.036	0.003	0.14	B
D82G	79	100	591	0.10	0.000	0.018	0.000	0.000	0.003	0.000	0.022	0.003	0.22	C
D82H	60	100	819	0.10	0.000	0.026	0.000	0.000	0.001	0.015	0.042	0.016	0.42	D
D82J	29	100	1377	0.10	0.000	0.043	0.000	0.000	0.000	0.000	0.043	0.000	0.43	D
Total			**5824**	**0.80**	**0.000**	**0.181**	**0.000**	**0.000**	**0.016**	**0.017**	**0.215**	**0.033**		

Table 4-51 Richtersveld: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D82A	69.43	0	0.005	0.005	**-0.013***			Low
D82D	4.06	0	0.001	0.001	0.002			Low
D82E	47.29	0	0.004	0.004	0.118			Low
D82F	8.09	0	0.004	0.004	0.148			Low
D82G	6.29	0	0.004	0.004	0.049			Low
D82H	96.87	0	0.002	0.002	0.037			Intermediate
D82J	34.83	0	0.000	0.000	0.037			Low

* Red text indicates negative allocable groundwater, therefore the quat is already over utilised.

Table 4-52 Richtersveld: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D82A	0	1	1	2	2	0	17	17	33	33	33
D82D	1	4	8	7	3	4	17	35	30	13	57
D82E	0	0	1	0	0	0	0	100	0	0	100
D82F	0	0	1	1	0	0	0	50	50	0	50
D82G	0	0	0	1	3	0	0	0	25	75	0
D82H	0	0	3	1	1	0	0	60	20	20	60

4.3.18 Namaqualand Coastal

The GRU consists of succulent Karoo vegetation and dune veld on the arid coastal plain, with all catchments draining directly to the Atlantic Ocean (Figures 4.72 and 4.73).

The GRU is underlain by rocks of the Nama and Vanrhynsdorp groups, which are covered by Tertiary and Quaternary sediments. Recharge is from less than 1 mm to 2 mm. The aquifer is of the fractured and weathered type but mean borehole yields are very low, being less than 0.1 l/s. Groundwater levels are from 40 - 50 mbgl.

Groundwater is generally of Class 3 and 4, Poor to Unacceptable, except in the north, in F40A and F40D, where Class 2 and 3 water exist. The potability of groundwater is less than 30% (Table 4.55).

The aquifer is a sole source of supply for Kleinzee, Hondeklipbaai and Kolingnaas. Groundwater use is primarily for livestock and water supply (Table 4.53). The stress index is low to moderate due to the small population and very low recharge rates.

The GRU moderately to heavily dependent on groundwater despite the poor quality, as no surface water source is available. The catchments are considered to be of low importance due to the low to moderate stress indices (Table 4.54).

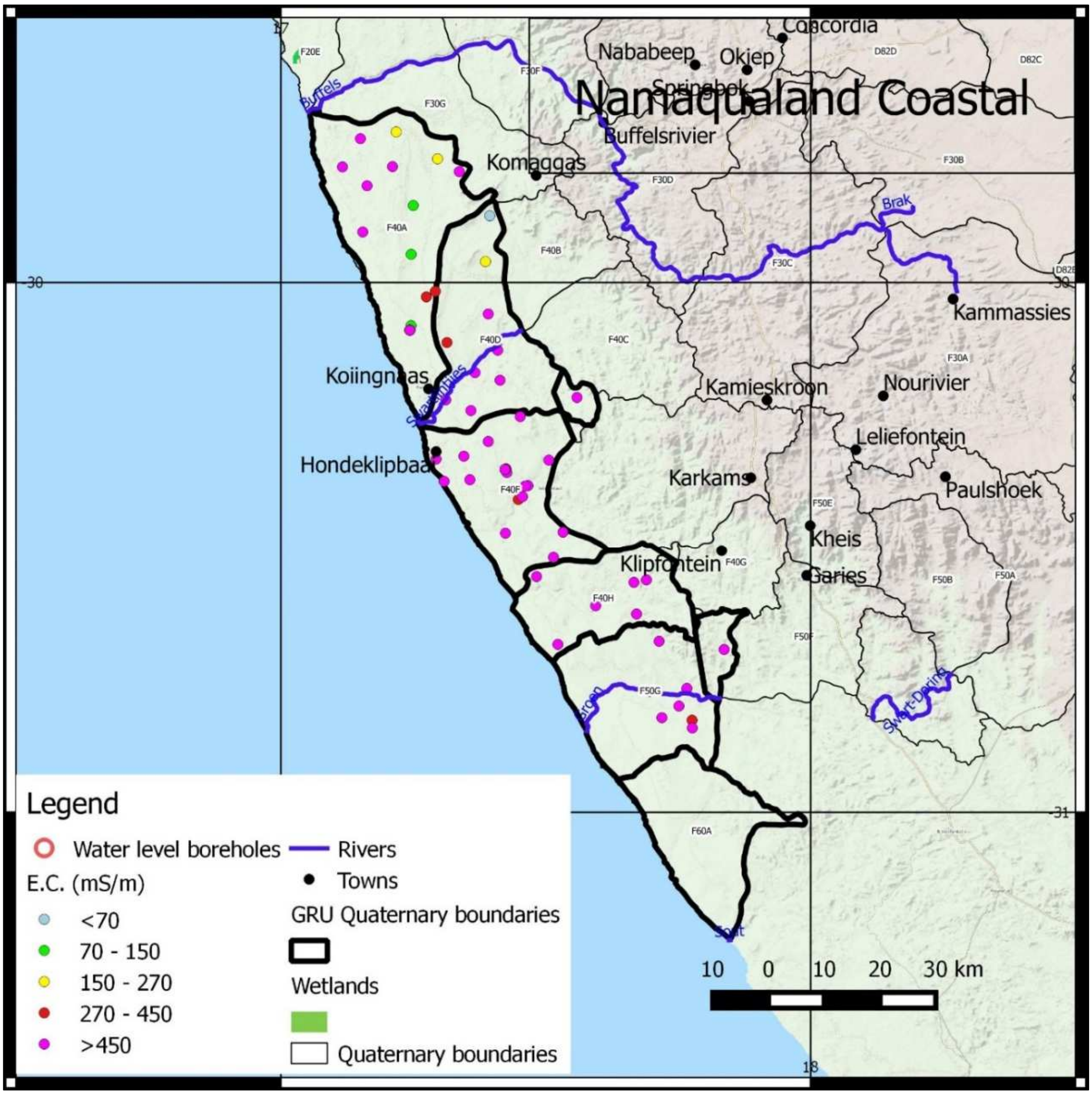


Figure 4.72 Catchments in Namaqualand Coastal GRU and existing monitoring boreholes

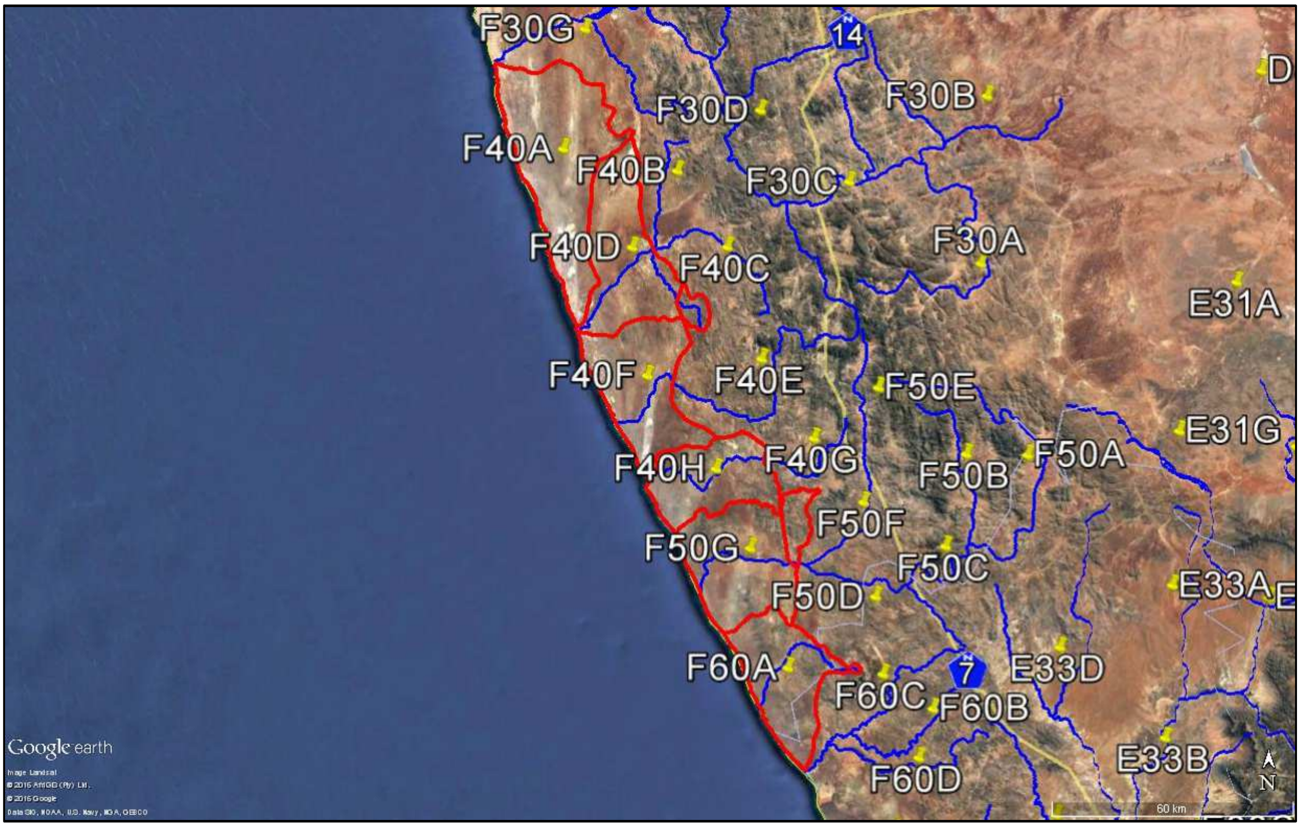


Figure 4.73 Namaqualand Coastal land cover

Table 4-53 Namaqualand Coastal: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
F40A	118	100	1015	1.49	0.000	0.043	0.084	0.000	0.004	0.077	0.208	0.081	0.14	B
F40D	123	100	739	0.95	0.000	0.033	0.000	0.000	0.002	0.001	0.036	0.003	0.04	A
F40F	118	100	681	0.70	0.000	0.030	0.000	0.000	0.035	0.067	0.132	0.102	0.19	B
F40H	109	100	513	0.14	0.000	0.023	0.000	0.000	0.001	0.000	0.024	0.001	0.17	B
F50G	96	100	774	0.17	0.000	0.034	0.013	0.000	0.002	0.000	0.050	0.002	0.30	C
F60A	103	100	572	0.14	0.000	0.009	0.000	0.000	0.004	0.026	0.039	0.030	0.28	C
Total				**3.58**	**0.000**	**0.172**	**0.097**	**0.000**	**0.048**	**0.171**	**0.488**	**0.219**		

Table 4-54 Namaqualand Coastal: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
F40A	88.89	0	0.005	0.005	0.831			Low
F40D	62.3	0	0.003	0.003	0.591			Low
F40F	97.31	0	0.045	0.045	0.363			Low
F40H	73.68	0	0.002	0.002	0.074			Low
F50G	73.68	0	0.003	0.003	0.077			Low
F60A	81.59	0	0.005	0.005	0.065			Low

Table 4-55 Namaqualand Coastal: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
F40A	0	3	2	3	6	0	21	14	21	43	36
F40D	1	0	1	1	7	10	0	10	10	70	20
F40F	0	0	0	1	18	0	0	0	5	95	0
F40H	0	0	0	0	7	0	0	0	0	100	0
F50G	0	0	0	1	6	0	0	0	14	86	0
F60A											

4.3.19 Karoo Sandstone and Shale Southwest

The GRU consists of the Karoo escarpment zone, which forms the headwater regions of the Vis and Riet rivers (Figures 4.74 and 4.75).

The Karoo sandstones and shales of the Beaufort Group overlie the Ecca Group. Small volumes of baseflow potentially exist in the Sutherland vicinity due to higher rainfall; however, any baseflow is lost further down the channel. Recharge increases from 3 - 8 mm/a from north to south, being highest near Sutherland. The aquifer is of the fractured type and mean borehole yields are 1.5 - 2.5 l/s, hence the aquifer is moderately productive. Groundwater levels are from 5 - 13 mbgl.

Groundwater quality is of Class 1 - 2, however, high fluorides can be encountered. The potability of groundwater is over 90% (Table 4.58).

The aquifer is a sole source of supply for Sutherland. Groundwater use is primarily for irrigation, however, water supply to Sutherland is a significant component of the water use (Table 4.56). The stress index is low, but is moderate in D51A due to irrigation and water supply to Sutherland. Groundwater levels in D51A indicate dropping water levels 12 m below original water levels, despite only a moderate stress index, suggesting that localised dewatering is occurring due to local aquifers not being connected hydraulically to the remainder of the catchment (Figure 4.76).

The GRU is highly dependent on groundwater for water supply, consequently, catchment D51A with a dropping water level is considered of high priority (Table 4.57).

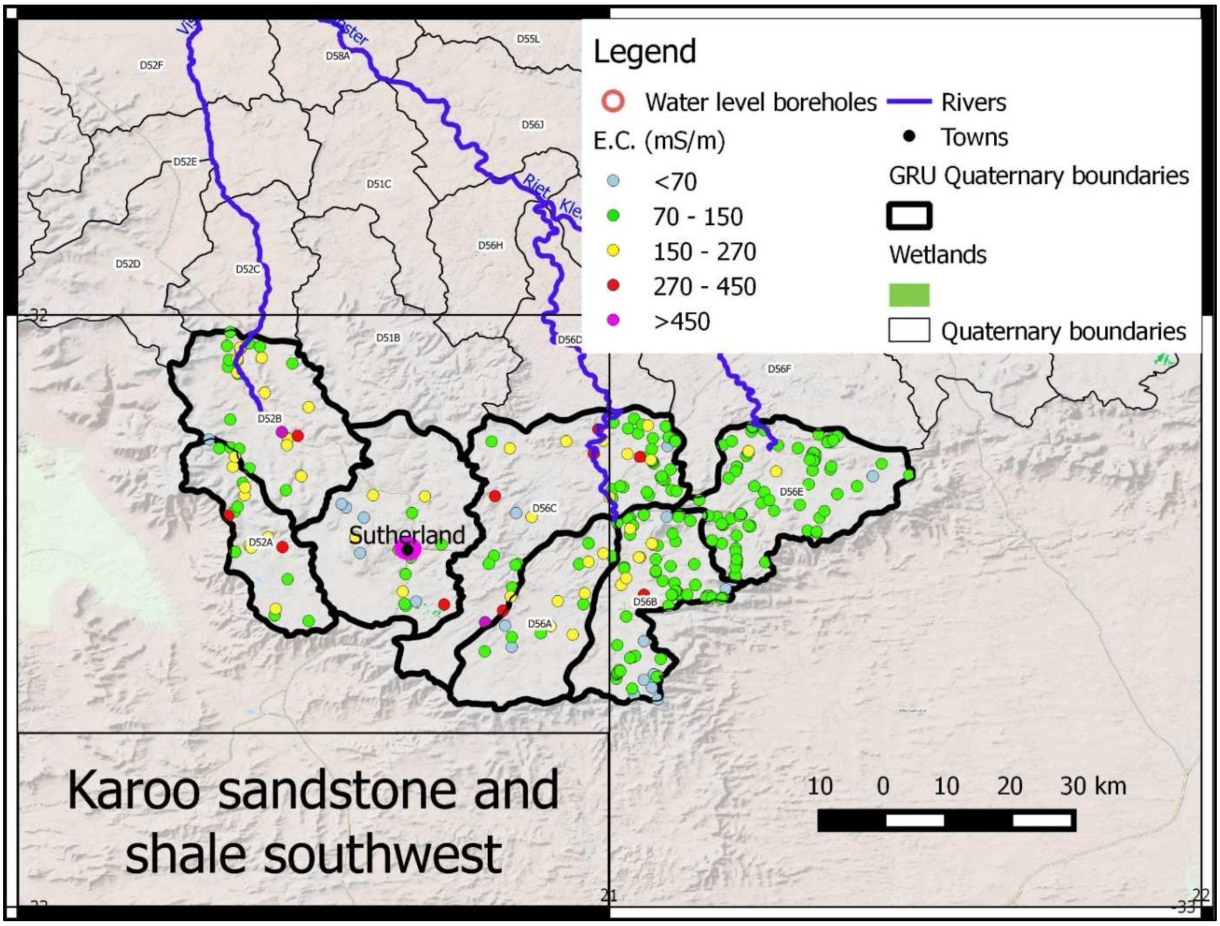


Figure 4.74 Catchments in Karoo Sandstone and Shale Southwest GRU and existing monitoring boreholes

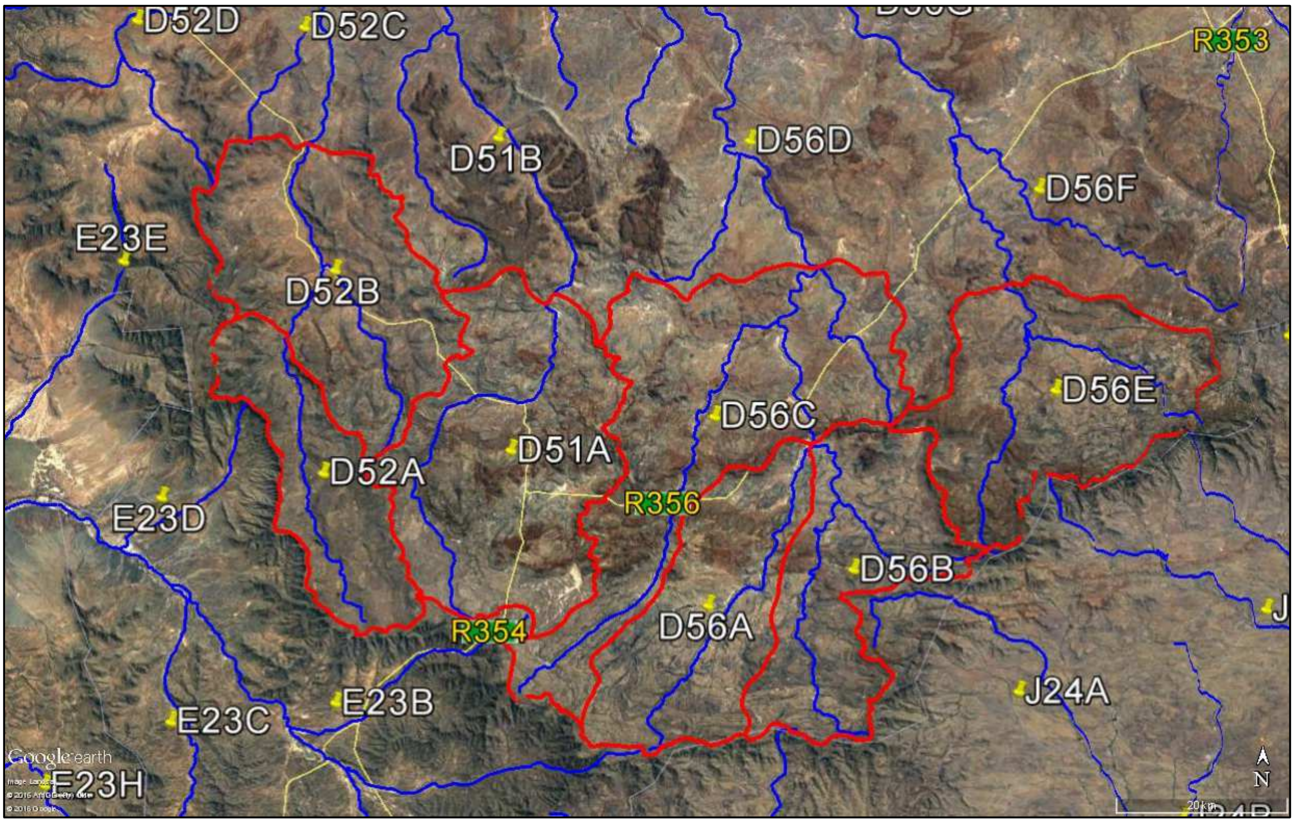


Figure 4.75 Karoo Sandstone and Shale Southwest land cover

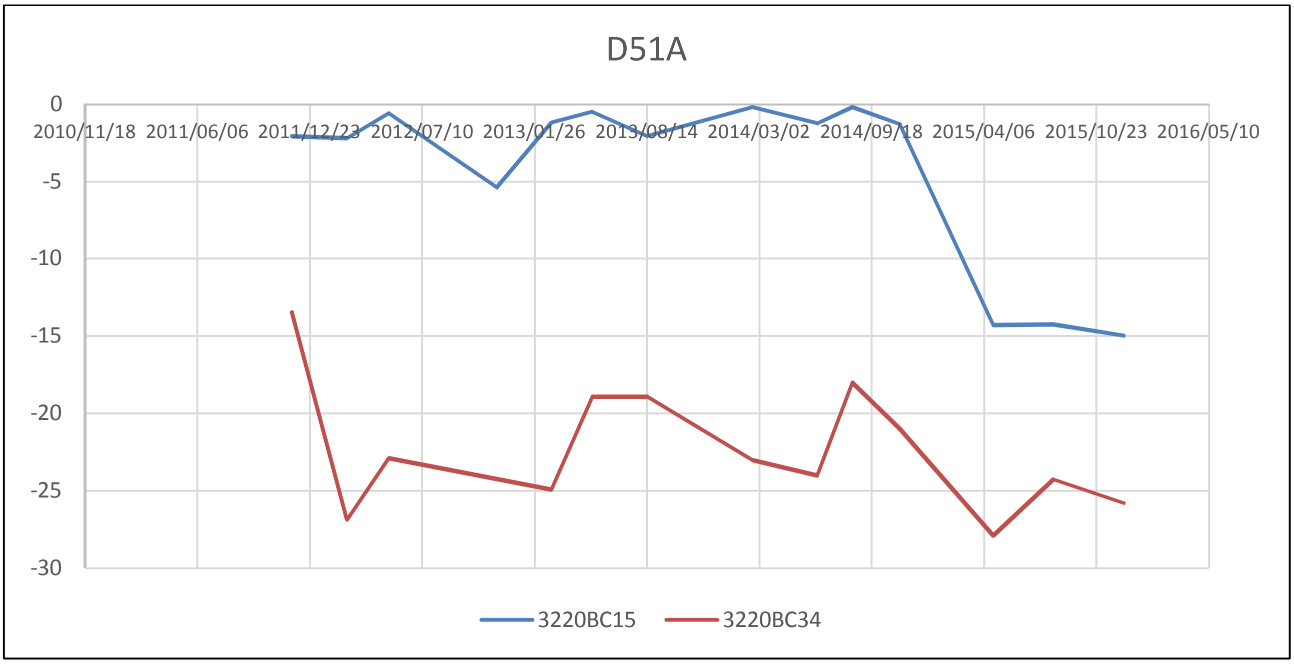


Figure 4.76 Water levels in D51A in mbgl

Table 4-56 Karoo Sandstone and Shale Southwest: Groundwater use and stress index

Quat	MAP	% of Quat	Area (km²)	Recharge (Mm³/a)	Groundwater use (Mm³/a)								Stress Index	Present Status Category
					Irrigation	Livestock	Mining	Industry	Schedule 1	Regional schemes	Total	Domestic		
D51A	312	100	797	5.05	0.818	0.028	0.000	0.130	0.012	0.150	1.138	0.162	0.23	C
D52A	319	100	378	3.06	0.266	0.013	0.000	0.000	0.003	0.000	0.282	0.003	0.09	B
D52B	267	100	660	3.29	0.428	0.023	0.000	0.000	0.004	0.000	0.455	0.005	0.14	B
D56A	292	100	510	3.00	0.024	0.018	0.000	0.000	0.004	0.000	0.045	0.004	0.02	A
D56B	266	100	519	2.46	0.130	0.018	0.000	0.000	0.004	0.000	0.151	0.004	0.06	B
D56C	245	100	920	3.01	0.008	0.032	0.000	0.000	0.006	0.000	0.047	0.007	0.02	A
D56E	229	100	666	1.41	0.000	0.036	0.000	0.000	0.005	0.000	0.041	0.005	0.03	A
Total			**4449**	**21.29**	**1.674**	**0.169**	**0.000**	**0.130**	**0.037**	**0.151**	**2.160**	**0.188**		

Table 4-57 Karoo Sandstone and Shale Southwest: Groundwater Reserve and allocable groundwater

Quat	GW dependency (%)	GW EWR (Mm³)	BHN (Mm³)	GW component of the Reserve (Mm³)	Allocable GW (Mm³)	Water level stability (Y/N)	Water level drop (m)	Priority
D51A	99.64	0.1594	0.175	0.334	2.438	Y	12	High
D52A	92.15	0	0.003	0.003	1.808			Low
D52B	92.15	0	0.006	0.006	1.840			Low
D56A	92.15	0	0.005	0.005	1.922			Low
D56B	92.06	0	0.005	0.005	1.503			Low
D56C	92.15	0	0.008	0.008	1.928			Low
D56E	92.15	0	0.006	0.006	0.888			Low

Table 4-58 Karoo Sandstone and Shale Southwest: Water quality distribution

Quat	Class 0	Class 1	Class 2	Class 3	Class 4	Class 0	Class 1	Class 2	Class 3	Class 4	Potable (%)
	Number of boreholes					% of boreholes					
D51A	6	9	5	2	0	27	41	23	9	0	91
D52A	1	8	8	2	0	5	42	42	11	0	92
D52B	0	14	10	1	1	0	54	38	4	4	95
D56A	2	7	6	0	0	13	47	40	0	0	100
D56B	10	60	7	2	0	13	76	9	3	0	97
D56C	2	35	9	5	1	4	67	17	10	2	88
D56E	3	81	2	0	0	3	94	2	0	0	100

5 SUMMARY AND CONCLUSIONS

5.1 SUMMARY OF GROUNDWATER RESERVE

A summary table of values for all Quaternaries and Sub-quaternaries is given in table 5.1.

5.2 PRIORITISED GRUS

The continued functioning of stressed regions dependent on groundwater requires intervention to prevent additional stresses. Several areas have been identified in Chapter 4 as being stressed in terms of high stress indices, declining water levels, and sole source dependency. These are depicted in Figure 5.1. Most of the priority catchments are located in the south, the Karoo sandstone and shale GRUs, which are the target area for potential fracking.

These GRUs are also classified as sole source aquifers for water supply, and highly dependent on groundwater with an already high stress index. Contamination or large abstractions from fracking or other activities could cause significant deterioration in water supply. The specification of Resource Quality Objectives (RQOs) for these GRUs will require additional and stringent RQO attributes.

The catchments rated as of High or Intermediate Priority are listed in Table 5.2. The Present Status Category of each Quaternary in each GRU is shown in Figure 5.2.

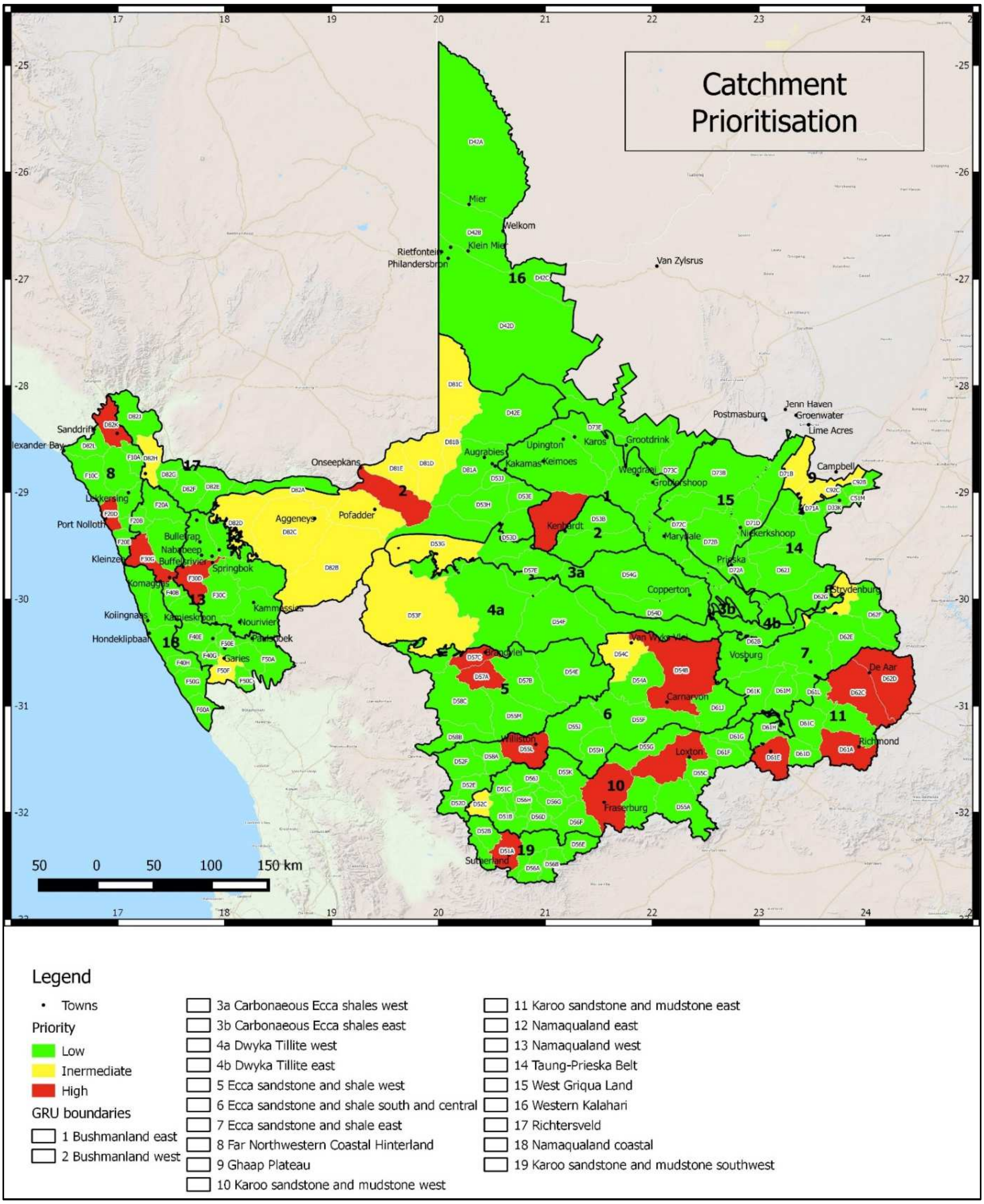


Figure 5.1 Catchment prioritisation of groundwater in the Lower Orange WMA

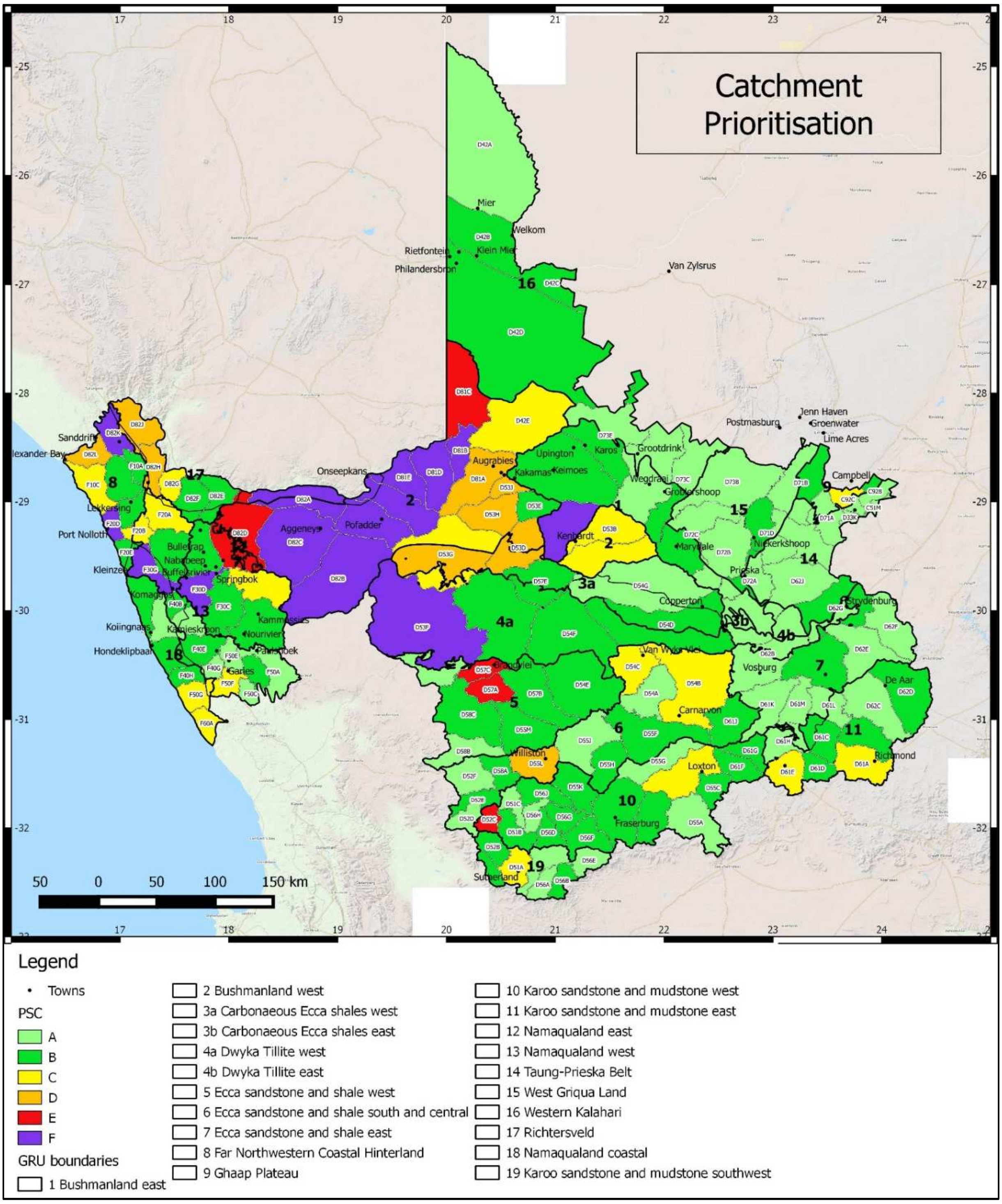


Figure 5.2 Present Status Category of groundwater in the Lower Orange WMA

Table 5-1 Summary of Groundwater Reserve

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D53C	Bushmanland east	1899	100	0.32	5870	0	0.018	0.018	5.625	0.342	**-0.018***	1.08	F
D62H	Bushmanland east	1037	50	4.37	174	0	0.011	0.011	0.252	0.208	2.703	0.05	A
D72A	Bushmanland east	273	20	0.95	444	0	0.004	0.004	0.421	0.008	0.611	0.01	A
D72B	Bushmanland east	416	16	1.26	2111	0	0.009	0.009	0.714	0.013	0.809	0.01	A
D72C	Bushmanland east	1393	50	2.63	1676	0	0.027	0.027	1.027	0.461	1.409	0.17	B
D73C	Bushmanland east	881	36	2.89	1248	0	0.04	0.04	1.384	0.234	1.721	0.08	B
D73D	Bushmanland east	2116	56	1.39	7370	0	0.038	0.038	2.734	0.055	0.861	0.04	A
D73E	Bushmanland east	1634	48	1.02	11800	0	0.025	0.025	2.451	0.082	0.609	0.08	B
D73F	Bushmanland east	4630	100	0.97	96191	0	0.116	0.116	11.959	0.168	0.503	0.17	B
D42E	Bushmanland west	4208	100	0.69	3014	0	0.078	0.078	11.304	0.218	0.292	0.32	C
D53A	Bushmanland west	1939	100	0.42	787	0	0.018	0.018	4.286	0.089	0.215	0.21	C
D53B	Bushmanland west	1713	100	0.44	1014	0	0.017	0.017	3.864	0.106	0.216	0.24	C
D53D	Bushmanland west	833	45	0.1	717	0	0.007	0.007	7.000	0.058	0.025	0.59	D
D53E	Bushmanland west	826	100	0.36	735	0	0.007	0.007	1.944	0.046	0.205	0.13	B
D53G	Bushmanland west	1775	38	0.26	1355	0	0.014	0.014	5.385	0.078	0.116	0.3	C
D53H	Bushmanland west	1589	100	0.16	1403	0	0.013	0.013	8.125	0.089	0.046	0.55	D
D53J	Bushmanland west	455	100	0.05	1400	0	0.008	0.008	16.000	0.023	0.017	0.46	D
D81A	Bushmanland west	2310	100	0.22	9639	0	0.052	0.052	23.636	0.122	0.054	0.56	D
D81B	Bushmanland west	851	100	0.05	700	0	0.005	0.005	10.000	0.051	**-0.001***	1.02	F
D81C	Bushmanland west	2682	100	0.2	1789	0	0.022	0.022	11.000	0.146	0.03	0.74	E
D81D	Bushmanland west	1823	100	0.11	1604	0	0.015	0.015	13.636	0.102	0.001	0.96	F
D81E	Bushmanland west	1287	100	0.04	1298	0	0.011	0.011	27.500	0.057	**-0.011***	1.35	F
D81F	Bushmanland west	1839	100	0.05	2470	0	0.017	0.017	34.000	0.179	**-0.088***	3.8	F
D81G	Bushmanland west	2005	100	0.08	5427	0	0.013	0.013	16.250	0.081	**-0.003***	1.02	F

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D82A	Bushmanland west	1015	53	0.01	524	0	0.006	0.006	60.000	0.077	**-0.042***	5.63	F
D82B	Bushmanland west	4873	100	0.08	598	0	0.019	0.019	23.750	0.165	**-0.060***	2.15	F
D82C	Bushmanland west	3991	100	0.07	2855	0	0.023	0.023	32.857	0.146	**-0.051***	2.03	F
D82D	Bushmanland west	1879	63	0.1	2903	0	0.011	0.011	11.000	0.067	0.021	0.66	E
D53D	Dwyka tillite	1009	55	0.12	869	0	0.008	0.008	6.667	0.045	0.047	0.37	C
D53G	Dwyka tillite	2244	47	0.33	1713	0	0.018	0.018	5.455	0.21	0.074	0.64	D
D54D	Dwyka tillite	2371	47	2.52	397	0	0.023	0.023	0.913	0.173	1.522	0.07	B
D54G	Dwyka tillite	4503	100	4.28	1140	0	0.048	0.048	1.121	0.152	2.676	0.04	A
D57E	Dwyka tillite	1218	62	0.61	840	0	0.012	0.012	1.967	0.055	0.360	0.09	B
D62B	Dwyka tillite	620	20	2.63	339	0	0.01	0.01	0.380	0.093	1.649	0.04	A
D62H	Dwyka tillite	497	24	2.09	83	0	0.005	0.005	0.239	0.03	1.339	0.01	A
D53F	Ecca Carbonaceous shales	7051	88	0.81	1060	0	0.044	0.044	5.432	1.188	**-0.25***	1.47	F
D53G	Ecca Carbonaceous shales	726	15	0.11	554	0	0.006	0.006	5.455	0.032	0.05	0.3	C
D54D	Ecca Carbonaceous shales	2698	53	2.87	452	0	0.026	0.026	0.906	0.262	1.69	0.09	B
D54F	Ecca Carbonaceous shales	3809	100	2.93	446	0	0.036	0.036	1.229	0.231	1.75	0.08	B
D57D	Ecca Carbonaceous shales	4444	100	1.85	2100	0	0.057	0.057	3.081	0.364	0.96	0.2	B
D57E	Ecca Carbonaceous shales	740	38	0.37	510	0	0.007	0.007	1.892	0.051	0.21	0.14	B
D62B	Ecca Carbonaceous shales	560	18	2.38	306	0	0.009	0.009	0.378	0.064	1.5	0.03	A
D62G	Ecca Carbonaceous shales	517	20	3.27	705	0	0.041	0.041	1.254	0.067	2.08	0.02	A
D62H	Ecca Carbonaceous shales	527	26	2.22	88	0	0.006	0.006	0.270	0.032	1.42	0.01	A
D61H	Ecca sandstone and shale east	300	28	1.46	56	0	0.004	0.004	0.274	0.026	0.935	0.02	A
D61J	Ecca sandstone and shale east	1557	100	5.99	246	0	0.02	0.02	0.334	0.302	3.696	0.05	B

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D61K	Ecca sandstone and shale east	1607	100	7.54	250	0	0.02	0.02	0.265	0.175	4.787	0.02	A
D61L	Ecca sandstone and shale east	511	50	3.71	96	0	0.008	0.008	0.216	0.059	2.371	0.02	A
D61M	Ecca sandstone and shale east	942	100	5.88	175	0	0.015	0.015	0.255	0.199	3.688	0.03	A
D62A	Ecca sandstone and shale east	2240	100	11.71	5667	0	0.078	0.078	0.666	0.69	7.15	0.06	B
D62B	Ecca sandstone and shale east	1934	62	8.22	1058	0	0.027	0.027	0.328	0.296	5.146	0.04	A
D62E	Ecca sandstone and shale east	1920	100	15.51	365	0	0.031	0.031	0.200	0.556	9.717	0.04	A
D62F	Ecca sandstone and shale east	1698	100	19.42	361	0	0.028	0.028	0.144	0.482	12.305	0.02	A
D62G	Ecca sandstone and shale east	812	32	5.14	1108	0	0.059	0.059	1.148	0.277	3.156	0.05	B
D52D	Ecca sandstone and shale south and central	638	100	2.63	75	0	0.006	0.006	0.228	0.085	1.651	0.03	A
D52E	Ecca sandstone and shale south and central	609	100	1.84	71	0	0.006	0.006	0.326	0.286	1.009	0.16	B
D52F	Ecca sandstone and shale south and central	1146	100	1.9	134	0	0.011	0.011	0.579	0.009	1.231	0	A
D54A	Ecca sandstone and shale south and central	1518	100	1.82	181	0	0.015	0.015	0.824	0.111	1.109	0.06	B
D54B	Ecca sandstone and shale south and central	4051	100	6.97	8789	0	0.068	0.068	0.976	1.83	3.334	0.26	C
D54C	Ecca sandstone and shale south and central	1342	100	0.88	160	0	0.013	0.013	1.477	0.198	0.442	0.22	C
D55F	Ecca sandstone and shale south and central	2631	100	4.48	404	0	0.032	0.032	0.714	0.271	2.734	0.06	B
D55H	Ecca sandstone and shale south and central	1151	100	1.33	121	0	0.01	0.01	0.752	0.123	0.781	0.09	B
D55J	Ecca sandstone and shale south and central	1998	100	2.63	208	0	0.018	0.018	0.684	0.046	1.677	0.02	A
D55L	Ecca sandstone and shale south and central	1242	100	1.71	3489	0	0.021	0.021	1.228	0.956	0.489	0.56	D

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D58A	Ecca sandstone and shale south and central	763	100	0.77	88	0	0.007	0.007	0.909	0.042	0.47	0.06	B
D53F	Ecca sandstone and shale west	986	12	0.11	148	0	0.01	0.01	9.091	0.005	0.069	0.05	A
D54E	Ecca sandstone and shale west	3326	100	2.7	361	0	0.03	0.03	1.111	0.257	1.585	0.1	B
D55M	Ecca sandstone and shale west	1813	100	0.86	190	0	0.02	0.02	2.326	0.08	0.506	0.09	B
D57A	Ecca sandstone and shale west	853	100	0.26	95	0	0.01	0.01	3.846	0.222	0.022	0.86	E
D57B	Ecca sandstone and shale west	2274	100	2.4	238	0	0.02	0.02	0.833	0.169	1.447	0.07	B
D57C	Ecca sandstone and shale west	637	100	0.19	1462	0	0.01	0.01	5.263	0.145	0.029	0.75	E
D58B	Ecca sandstone and shale west	1131	100	1.71	345	0	0.01	0.01	0.585	0.025	1.095	0.01	A
D58C	Ecca sandstone and shale west	2520	100	0.99	292	0	0.02	0.02	2.020	0.099	0.578	0.1	B
D82K	Far Northwestern Coastal Hinterland	913	100	0.04	1072	0	0.01	0.01	25.000	0.101	**-0.04***	2.63	F
D82L	Far Northwestern Coastal Hinterland	748	100	0.07	3282	0	0.008	0.008	11.429	0.03	0.02	0.44	D
F10A	Far Northwestern Coastal Hinterland	458	100	0.12	8	0	0	0	0.000	0.021	0.06	0.17	B
F10B	Far Northwestern Coastal Hinterland	1085	100	0.26	18	0	0.001	0.001	0.385	0.049	0.14	0.19	B
F10C	Far Northwestern Coastal Hinterland	1173	100	0.19	20	0	0.001	0.001	0.526	0.052	0.09	0.27	C
F20B	Far Northwestern Coastal Hinterland	122	24	0.02	8	0	0	0	0.000	0.006	0.01	0.25	C
F20C	Far Northwestern Coastal Hinterland	611	100	0.28	373	0	0.009	0.009	3.214	0.055	0.15	0.19	B
F20D	Far Northwestern Coastal Hinterland	452	100	0.15	5551	0	0.001	0.001	0.667	0.43	**-0.18***	2.78	F

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
F20E	Far Northwestern Coastal Hinterland	432	100	0.29	29	0	0	0	0.000	0.021	0.17	0.07	B
C92B	Ghaap Plateau	191	30	1.45	647	0	0.032	0.032	2.207	0.094	0.88	0.06	B
C92C	Ghaap Plateau	410	66	3.93	16743	0	0.095	0.095	2.417	0.87	1.974	0.22	C
D71A	Ghaap Plateau	436	36	3.01	155	0	0.008	0.008	0.266	0.072	1.909	0.02	A
D71B	Ghaap Plateau	1000	38	7.41	2851	0	0.03	0.03	0.405	0.737	4.331	0.1	B
D61A	Karoo sandstone and shale east	1464	100	8.46	5398	0	0.041	0.041	0.485	2.195	4.069	0.26	C
D61B	Karoo sandstone and shale east	1196	100	5.81	271	0	0.019	0.019	0.327	0.573	3.404	0.1	B
D61C	Karoo sandstone and shale east	1169	100	6.96	215	0	0.017	0.017	0.244	0.397	4.264	0.06	B
D61D	Karoo sandstone and shale east	650	100	2.66	119	0	0.01	0.01	0.376	0.514	1.392	0.19	B
D61E	Karoo sandstone and shale east	1090	100	5.99	8801	0	0.036	0.036	0.601	1.443	2.949	0.24	C
D61F	Karoo sandstone and shale east	873	100	2.79	160	0	0.013	0.013	0.466	0.237	1.659	0.08	B
D61G	Karoo sandstone and shale east	743	100	2.88	138	0	0.011	0.011	0.382	0.302	1.677	0.1	B
D61H	Karoo sandstone and shale east	785	72	3.83	146	0	0.012	0.012	0.313	0.151	2.388	0.04	A
D61L	Karoo sandstone and shale east	504	50	3.76	95	0	0.008	0.008	0.213	0.059	2.405	0.02	A
D62C	Karoo sandstone and shale east	2126	100	15.81	1473	0	0.048	0.048	0.304	0.488	9.951	0.03	A
D62D	Karoo sandstone and shale east	2397	100	28.5	29400	0	0.091	0.091	0.319	4.299	15.719	0.15	B
D51A	Karoo sandstone and shale southwest	797	100	5.05	2917	0.1594	0.175	0.334	6.614	1.138	2.438	0.23	C
D52A	Karoo sandstone and shale southwest	378	100	3.06	40	0	0.003	0.003	0.098	0.282	1.808	0.09	B

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D52B	Karoo sandstone and shale southwest	660	100	3.29	67	0	0.006	0.006	0.182	0.455	1.84	0.14	B
D56A	Karoo sandstone and shale southwest	510	100	3	54	0	0.005	0.005	0.167	0.045	1.922	0.02	A
D56B	Karoo sandstone and shale southwest	519	100	2.46	56	0	0.005	0.005	0.203	0.151	1.503	0.06	B
D56C	Karoo sandstone and shale southwest	920	100	3.01	97	0	0.008	0.008	0.266	0.047	1.928	0.02	A
D56E	Karoo sandstone and shale southwest	666	100	1.41	70	0	0.006	0.006	0.426	0.041	0.888	0.03	A
D51B	Karoo sandstone and shale west	873	100	2.54	91	0	0.008	0.008	0.315	0.48	1.335	0.19	B
D51C	Karoo sandstone and shale west	522	100	0.82	55	0	0.005	0.005	0.610	0.012	0.523	0.01	A
D52C	Karoo sandstone and shale west	465	100	0.63	49	0	0.004	0.004	0.635	0.467	0.103	0.74	E
D55A	Karoo sandstone and shale west	1872	100	4.97	572	0	0.05	0.05	1.006	0.106	3.154	0.02	A
D55B	Karoo sandstone and shale west	1259	100	3.01	135	0	0.011	0.011	0.365	0.281	1.77	0.09	B
D55C	Karoo sandstone and shale west	760	100	2.96	210	0	0.015	0.015	0.507	0.207	1.788	0.07	B
D55D	Karoo sandstone and shale west	1889	100	4.51	1351	0	0.031	0.031	0.687	1.262	2.107	0.28	C
D55E	Karoo sandstone and shale west	2240	100	3.16	3254	0	0.029	0.029	0.918	0.358	1.82	0.11	B
D55G	Karoo sandstone and shale west	1293	100	1.93	195	0	0.016	0.016	0.829	0.091	1.195	0.05	A
D55K	Karoo sandstone and shale west	1247	100	1.4	131	0	0.011	0.011	0.786	0.095	0.847	0.07	B
D56D	Karoo sandstone and shale west	621	100	0.93	64	0	0.005	0.005	0.538	0.074	0.556	0.08	B

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D56F	Karoo sandstone and shale west	1038	100	1.61	107	0	0.009	0.009	0.559	0.282	0.861	0.18	B
D56G	Karoo sandstone and shale west	651	100	0.91	67	0	0.006	0.006	0.659	0.054	0.555	0.06	B
D56H	Karoo sandstone and shale west	447	100	0.47	47	0	0.004	0.004	0.851	0.018	0.296	0.04	A
D56J	Karoo sandstone and shale west	931	100	1.24	97	0	0.008	0.008	0.645	0.086	0.749	0.07	B
F40A	Namaqualand coastal	1015	100	1.49	715	0	0.005	0.005	0.336	0.208	0.831	0.14	B
F40D	Namaqualand coastal	739	100	0.95	66	0	0.003	0.003	0.316	0.036	0.591	0.04	A
F40F	Namaqualand coastal	681	100	0.7	534	0	0.045	0.045	6.429	0.132	0.363	0.19	B
F40H	Namaqualand coastal	513	100	0.14	26	0	0.002	0.002	1.429	0.024	0.074	0.17	B
F50G	Namaqualand coastal	774	100	0.17	39	0	0.003	0.003	1.765	0.05	0.077	0.3	C
F60A	Namaqualand coastal	572	100	0.14	497	0	0.005	0.005	3.571	0.039	0.065	0.28	C
D82D	Namaqualand east	915	31	0.05	1414	0	0.005	0.005	10.000	0.033	0.01	0.66	E
F30A	Namaqualand east	1951	100	1.24	1755	0	0.027	0.027	2.177	0.169	0.694	0.14	B
F30B	Namaqualand east	1460	100	0.38	322	0	0.007	0.007	1.842	0.095	0.184	0.25	C
F30C	Namaqualand east	1651	100	1.94	2639	0	0.015	0.015	0.773	0.245	1.102	0.13	B
F30D	Namaqualand east	974	100	0.62	12107	0	0.012	0.012	1.935	1.119	**-0.326***	1.8	F
F30E	Namaqualand east	1257	100	0.69	21518	0	0.019	0.019	2.754	0.093	0.386	0.13	B
F20A	Namaqualand west	1117	100	0.25	63	0	0.002	0.002	0.800	0.052	0.132	0.2	C
F20B	Namaqualand west	391	76	0.08	27	0	0.001	0.001	1.250	0.018	0.039	0.23	C
F30F	Namaqualand west	1465	100	0.41	187	0	0.005	0.005	1.220	0.072	0.221	0.17	B
F30G	Namaqualand west	977	100	0.23	3502	0	0.008	0.008	3.478	1.068	**-0.544***	4.57	F
F40B	Namaqualand west	403	100	0.15	59	0	0.002	0.002	1.333	0.02	0.086	0.13	B
F40C	Namaqualand west	607	100	1.14	315	0	0.009	0.009	0.789	0.046	0.711	0.04	A
F40E	Namaqualand west	1062	100	2.01	2062	0	0.011	0.011	0.547	0.148	1.207	0.07	B
F40G	Namaqualand west	347	100	0.68	485	0	0.003	0.003	0.441	0.02	0.43	0.03	A

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
F50A	Namaqualand west	1303	100	1.09	1852	0	0.017	0.017	1.560	0.049	0.677	0.04	A
F50B	Namaqualand west	603	100	0.81	30	0	0.002	0.002	0.247	0.051	0.494	0.06	B
F50C	Namaqualand west	438	100	0.57	231	0	0.004	0.004	0.702	0.026	**0.353**	0.05	A
F50E	Namaqualand west	486	100	1.6	971	0	0.007	0.007	0.438	0.036	**1.015**	0.02	A
F50F	Namaqualand west	574	100	1.36	2028	0	0.005	0.005	0.368	0.378	**0.638**	0.28	C
D82A	Richtersveld	894	47	0.01	462	0	0.005	0.005	50.000	0.031	**-0.013***	2.58	F
D82D	Richtersveld	167	6	0.01	259	0	0.001	0.001	10.000	0.006	0.002	0.66	E
D82E	Richtersveld	939	100	0.22	157	0	0.004	0.004	1.818	0.035	0.118	0.16	B
D82F	Richtersveld	1036	100	0.26	588	0	0.004	0.004	1.538	0.036	0.148	0.14	B
D82G	Richtersveld	591	100	0.1	698	0	0.004	0.004	4.000	0.022	0.049	0.22	C
D82H	Richtersveld	819	100	0.1	544	0	0.002	0.002	2.000	0.042	0.037	0.42	D
D82J	Richtersveld	1377	100	0.1	9	0	0	0	0.000	0.043	0.037	0.43	D
C51M	Taung-Prieska belt	119	100	0.84	648	0	0.033	0.033	3.929	0.027	0.523	0.03	A
C92B	Taung-Prieska belt	446	70	3.4	1512	0	0.074	0.074	2.176	0.122	2.121	0.04	A
C92C	Taung-Prieska belt	211	34	2.02	8593	0	0.049	0.049	2.426	0.054	1.268	0.03	A
D33K	Taung-Prieska belt	158	100	1.44	1334	0	0.01	0.01	0.694	0.012	0.924	0.01	A
D62G	Taung-Prieska belt	1216	48	7.7	1660	0	0.097	0.097	1.260	0.91	4.398	0.12	B
D62J	Taung-Prieska belt	2198	100	10.13	427	0	0.027	0.027	0.267	0.304	6.384	0.03	A
D71A	Taung-Prieska belt	772	64	5.33	275	0	0.015	0.015	0.281	0.167	3.353	0.03	A
D71B	Taung-Prieska belt	392	15	2.9	1118	0	0.012	0.012	0.414	0.095	1.824	0.03	A
D71C	Taung-Prieska belt	1358	85	5.98	381	0	0.022	0.022	0.368	0.125	3.805	0.02	A
D71D	Taung-Prieska belt	656	38	2.7	778	0	0.014	0.014	0.519	0.048	1.719	0.02	A
D72A	Taung-Prieska belt	789	56	2.75	1285	0	0.013	0.013	0.473	0.07	1.738	0.03	A
D71B	West Griqualand	1245	47	9.22	3550	0	0.038	0.038	0.412	0.368	5.75	0.04	A
D71C	West Griqualand	232	15	1.02	65	0	0.004	0.004	0.392	0.018	0.65	0.02	A
D71D	West Griqualand	1056	62	4.34	1254	0	0.023	0.023	0.530	0.471	2.42	0.11	B

Quaternary catchment	Resource Unit	Total Quat area (km2)	% of Quat area	Recharge (Mm3/yr)	Population	BF / GW EWR (Mm3/yr)	BHN (Mm3/yr)	Reserve[1] (Mm3/yr)	Reserve as % of recharge	Total GW use[1] (Mm3/yr)	Allocable Use[2] (Mm3/yr)	SI	PSC
D72A	West Griqualand	335	24	1.17	546	0	0.005	0.005	0.427	0.149	0.66	0.13	B
D72B	West Griqualand	2152	84	6.52	10931	0	0.046	0.046	0.706	0.235	4.08	0.04	A
D72C	West Griqualand	1382	50	2.61	1663	0	0.027	0.027	1.034	0.039	1.67	0.01	A
D73B	West Griqualand	3522	100	18.31	1519	0.11163	0.19	0.302	1.649	0.652	11.39	0.04	A
D42A	Western Kalahari	10273	100	19.79	454	0	0.028	0.028	0.141	0.194	12.732	0.01	A
D42B	Western Kalahari	3197	100	1.71	1272	0	0.031	0.031	1.813	0.143	1.017	0.08	B
D42C	Western Kalahari	1566	100	1.9	4580	0	0.183	0.183	9.632	0.362	1.104	0.19	B
D42D	Western Kalahari	14110	100	14.84	7150	0	0.155	0.155	1.044	1.037	8.979	0.07	B
D73C	Western Kalahari	1549	64	5.08	2194	0	0.063	0.063	1.240	0.195	3.172	0.04	A
D73D	Western Kalahari	1666	44	1.09	5800	0	0.03	0.03	2.752	0.043	0.677	0.04	A
D73E	Western Kalahari	1746	52	1.1	12609	0	0.027	0.027	2.455	0.053	0.674	0.05	A
TOTAL		251886		480.06	419409	0.27103	4.008	4.279		44.104	284.401		

1: Includes Schedule 1 use

2: 65% of recharge-Total Use- Reserve + Schehdule 1 (since Schedule 1 is an existing use and part of the reserve)

Table 5-2 High and Intermediate priority catchments

GRU	Catchment	Priority	GW dependency (%)	Stress index	Main stresses	Present Status Category	Water level decline (m)
Bushmanland East	D53C	High	77	1.08	Regional water schemes	F	6
Bushmanland West	D81B	Intermediate	6	1.02	Livestock	F	
	D81C	Intermediate	37	0.74	Livestock	E	3
	D81D	Intermediate	35	0.96	Livestock	F	
	D81E	Intermediate	28	1.35	Livestock	F	
	D81F	High	61	3.80	Livestock	F	
	D81G	Intermediate	3	1.02	Livestock	F	
	D82A	Intermediate	69	5.63	Livestock	F	
	D82B	Intermediate	40	2.15	Livestock	F	

GRU	Catchment	Priority	GW dependency (%)	Stress index	Main stresses	Present Status Category	Water level decline (m)
	D82C	Intermediate	9	2.03	Livestock	F	
	D82D	Intermediate	4	0.66	Livestock	E	
Dwyka Tillite	D53G	Intermediate	29	0.64	Livestock mining Regional schemes	D	
Carbonaceous Shale	D53F	Intermediate	51	1.47	Mining Industry	F	
Ecca Sandstone and Shale West	D57A	High	92	0.86	Irrigation	E	3
	D57C	High	98	0.75	Regional schemes	E	
Ecca Sandstone and Shale Central and Southwest	D54B	High	98	0.26	Irrigation Regional schemes	C	15
	D54C	Intermediate	87	0.22	Regional schemes	C	0
	D55L	High	99	0.56	Irrigation	D	10
Ecca Sandstone and Shale East	D62G	Intermediate	95	0.05	Regional schemes	B	5
Far Northwestern Coastal Hinterland	D82K	High	82	2.63	Regional schemes	F	
	F20D	High	55	2.78	Regional schemes	F	
Ghaap Plateau (dolomitic)	C92B	Intermediate	52	0.06	Dolomites	B	
	C92C	Intermediate	6	0.22		C	
	D71A	Intermediate	61	0.02		A	
	D71B	Intermediate	93	0.10		B	
Karoo Sandstone and Shale West	D52C	Intermediate	92	0.74	Irrigation	E	
	D55D	High	96	0.28	Irrigation Regional schemes	C	5
	D55E	High	99	0.11	Regional schemes	B	15
Karoo sandstone and Shale East	D61A	High	89	0.26	Irrigation Regional schemes	C	1
	D61E	High	96	0.24	Regional schemes Irrigation	C	
	D62C	High	96	0.03	Irrigation Regional schemes	A	2
	D62D	High	99	0.15	Regional schemes	B	2
Namaqualand East	F30D	High	55	1.8	Regional schemes	F	
Namaqualand West	F30G	High	94	4.57	Mining	F	
	F50F	Intermediate	96	0.28	Regional schemes	C	

GRU	Catchment	Priority	GW dependency (%)	Stress index	Main stresses	Present Status Category	Water level decline (m)
Richtersveld	D82H	Intermediate	97	0.42	Livestock Regional schemes	D	
Karoo sandstone and Shale Southwest	D51A	High	>99	0.23	Irrigation Regional schemes	C	12

6 REFERENCES

Dennis, I., Witthüsser, K., Vivier, K., Dennis, R. and Mavurayi, A. 2013. Groundwater Resource Directed Measures (2012 Edition). WRC Report TT506/12. Water Research Commission, Pretoria.

Department of Water Affairs and Forestry (DWAF). 2006a. Groundwater Resource Assessment Phase II (GRA II): Task 1D Groundwater Quantification. Version 2: Final. Prepared by DWAF, SRK, GEOSS and CSIR. Project 2003-150.

Department of Water Affairs and Forestry (DWAF), South Africa. 1996b. South African water quality guidelines. Volume 1: Domestic Use.

Department of Water Affairs and Forestry (DWAF). 1998. Quality of Domestic Water Supplies. Volume 1: Assessment Guide. Second Edition. Water Research Commission No: TT 101/98.

Department of Water Affairs (DWA), South Africa. 2011. Procedures to Develop and Implement Resource Quality Objectives. Department of Water Affairs, Pretoria, South Africa.

Lynch, S.D., Reynders, A.G., and Schulze, R.E., 1994. Preparing input data for a national-scale groundwater vulnerability map of Southern Africa. Water SA, 20 (3), 239–246.

Orange-Senqu River Commission (ORASECOM). 2011. Support to Phase 2 of the ORASECOM Basin-wide Integrated Water Resources Management Plan: Extension of Hydrology Records report. Prepared by WRP Consulting Engineers in association with Golder Associates, DMM, PIK, RAMBOLL and WCE.

Parsons, R.P. and Wentzel, J. 2006. Groundwater Resource Directed Measures (GRDM) Manual. A Water Research Commission project K5/1427 with support from FETWater. February 2006.

Pitman, W.V., Bailey, A.K., Kakebeeke, J.P. 2006. WRSM2000: Water Resources Simulation Model for Windows – User's Guide. Steward Scott Consulting Engineers and TiSD, Johannesburg.

Sami, K. 2014. Water Resources 2012: Sami Groundwater Module Verification Studies, Default Parameters and Calibration Guide.

Vegter, J.R. 2001. Groundwater development in South Africa and an Introduction to the Hydrogeology of groundwater Regions. WRC report No. TT/134/00.

7 APPENDIX A: COMMENTS REGISTER

	Section	Comments	Changes made?	Author comment
1	1.3.6	The ToR prescribed the calculation of the following statistical parameters for each quaternary catchment which we currently use: 10th percentile 50th percentile (median) 95th percentile Groundwater quality Reserve (Median +10%) that allows for reasonable contamination	Y	These calculations have beed added to the report. Tables 3.8, 3.9 and 3.10 were changed to this format
2	3.1	On page 3-1 the minimum precipitation was cited as 50mm/a but on page 3-5 it was cited as 20mm/a.	Y	One rainfall data set is gridded and the other one is averaged over the Quaternary, naturally, the gridded rainfall has values above and below the mean catchment rainfall.
3	2.2	Perhaps its better to avoid using Classify since Classification is a different process altogether and we can rather talk of categorisation	y	Wording changed to Delineate
	2.2	Perhaps we can put a clause of allocating with extreme caution rather than no allocation at all	y	Wording changed to include caution and monitoring
	2.3	Based on the definition stated here…. And what the NWA says its better also to cater for those with private boreholes as part of those under the BHN i.e. the Schedule 1. These are people who are reliant on the groundwater system	y	Reserve recalculated to include Schedule 1 users in reserve
	3.9.1	Is this statement talking about population itself or use?? Statement doesn’t make sense	Y	Wording corrected
	Figure 3.14	The 80-90 and 90-100 categories are difficult to differentiate on the map. Perhaps change the choice of the graduated colours	y	Map changed
	Table 3.1	Towns like Springbok, Kenhardt, Copperton do not use groundwater but from the Orange river	y	Towns that have a zero groundwater use listed have boreholes but also have a surface source, which was added. Kenhardt, listed as having boreholes that they utilise in the All towns studies in addition to surface water. Copperton is not listed in table 3.1. Springbok lists (Nama Khoi Muicipality lists 12 Boreholes for water supply service in WARMS. These could be used for municipal irrigation as
	Figure 3.15	Perhaps its better to swap the colours on the groundwater use legend such that high groundwater use is red just like what you did for the other maps eg 3.16 and 3.17	y	Figure changed
	3.11.3	2. Was this successfully done considering the poor rainfall runoff relationships for some of the resource units for instance Bushmanland, Far West Coastal and critically Namaqualand??	y	The number of corrections is 78 and the difference between the recharge for the study and in GRAII has been listed

	Section	Comments	Changes made?	Author comment
		For how many quaternary catchments was this technique adopted???		
	Fugure 3.27	Use colour ramp that is easy to differentiate	y	Figure changed
	Table 3.7	Is it a DWAF water quality guideline of 2006 or 1996? The 2006 guideline is NOT listed under References section! (If it exists).	y	Reference corrected to DWAF 1998 in references
	3.12	Please provide the full interpretation of the indices for easy interpretation rather than just talking of 2 categories when other categories like insignificant, very high and extreme are not mentioned	n	These categories are not discussed as none of the lower Orange fits within these categories
	3.12	What is the conclusion in terms of aquifer vulnerability in the WMA???	n	This was previously discussed when it was mentioned that only the dolomites are of moderate vulnerability and the rest of the catchment is of low vulnerability
	4	3. Some quaternary catchments are found in more than 1 resource unit eg D53G whose total area is 4 746 km^2. Part of it is in the Bushman West (1 775 km^2) and part of it lies in the Dwyka tillite (2244 km^2). As such in the tables for example 4.8 and 4.5 please include a column showing a percentage of each quat in that resource unit. This should apply to all GRU's.	y	A column of precent of the Quaternary in each GRU has been included in all the relevant tables
		4. The at the end of the report a consolidated table showing all the quaternary catchments in the WMA should be populated and provided as shown on the next page. 5. The Report lacks the conclusions and recommendations of the study!!	y	A summary table was added as part of the conclusions